SEWAGE AND INDUSTRIAL WASTES

(Formerly Sewage Works Journal)

JOURNAL of the FEDERATION OF SEWAGE AND INDUSTRIAL WASTES ASSOCIATIONS

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AUGUST, 1955—VOL. 27, No. 8

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28TH ANNUAL MEETING

OF THE

FEDERATION OF SEWAGE AND INDUSTRIAL WASTES ASSOCIATIONS

IN CONJUNCTION WITH

NEW JERSEY SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

AMBASSADOR HOTEL

ATLANTIC CITY, NEW JERSEY

October 10-13, 1955

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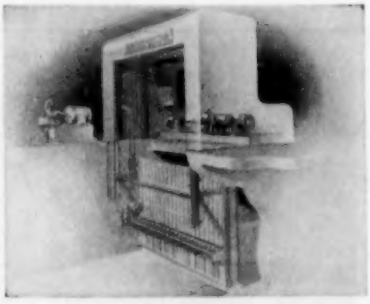

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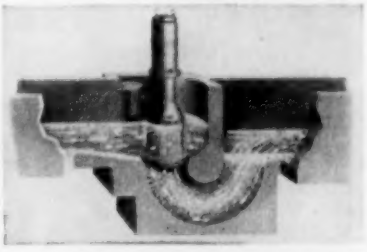

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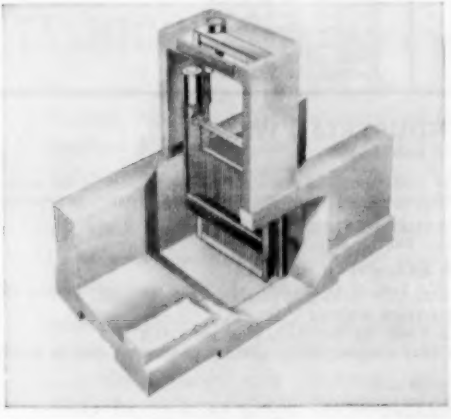

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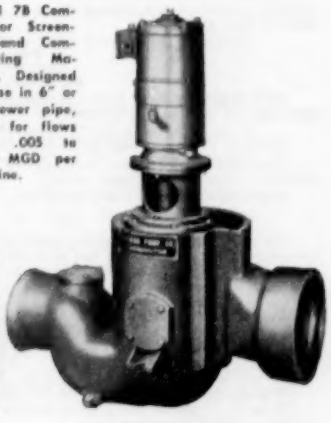

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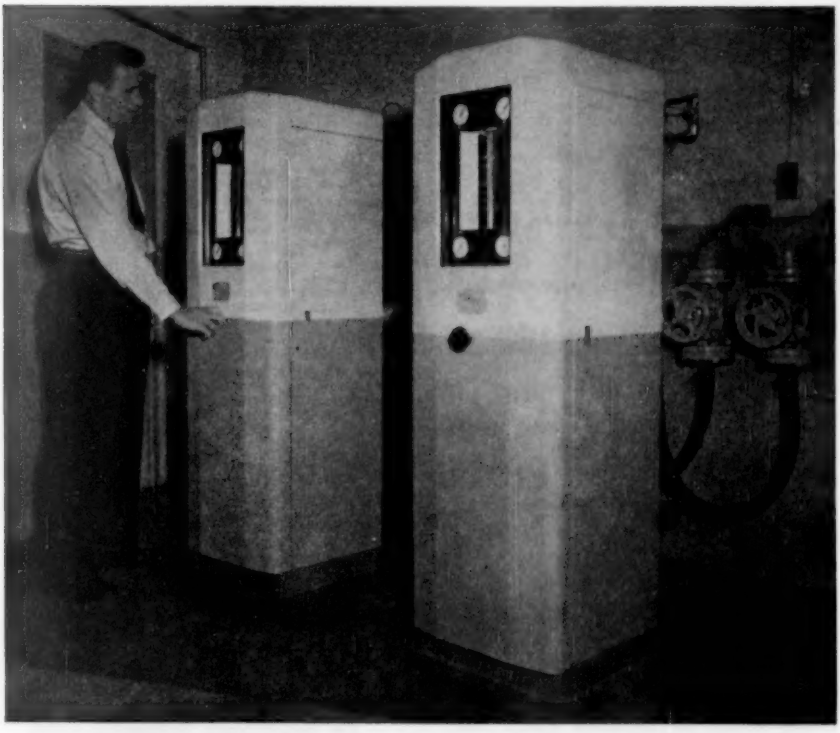

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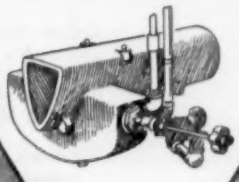

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Iowa Sewage Works Assn.	Hotel Waukonsa Fort Dodge, Iowa	Sept. 7–9, 1955
Kentucky–Tennessee Industrial Wastes and Sewage Works Assn.	Phoenix Hotel Lexington, Ky.	Sept. 12–14, 1955
Georgia Water and Sewage Assn.	Georgia Inst. Tech., Atlanta, Ga.	Sept. 21–23, 1955
South Dakota Water and Sewage Works Conf.	Brown Palace Hotel, Mobridge, S. Dak.	Sept. 21–23, 1955
Missouri Water and Sewerage Conf.	Connor Hotel, Joplin, Mo.	Sept. 25–27, 1955
New England Sewage and Industrial Wastes Assn.	Municipal Auditorium Webster, Mass.	Sept. 29, 1955
Oklahoma Water, Sewage and Industrial Wastes Conf.	Oklahoma A. and M. College Stillwater, Okla.	Oct. 5–6, 1955

TWENTY-EIGHTH ANNUAL MEETING

Federation of Sewage and Industrial Wastes Associations

in conjunction with

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Ambassador Hotel, Atlantic City, New Jersey

October 10–13, 1955

West Virginia Sewage and Industrial Wastes Assn.	Waldo Hotel, Clarksburg, W. Va.	Oct. 19–20, 1955
Nebraska Sewage and Industrial Wastes Assn.	Yancey Hotel Grand Island, Nebr.	Nov. 3–4, 1955
Florida Sewage and Industrial Wastes Assn.	Orange Court Hotel Orlando, Fla.	Nov. 6–9, 1955
North Carolina Sewage and Industrial Wastes Assn.	Robert E. Lee Hotel Winston Salem, N. C.	Nov. 14–16, 1955

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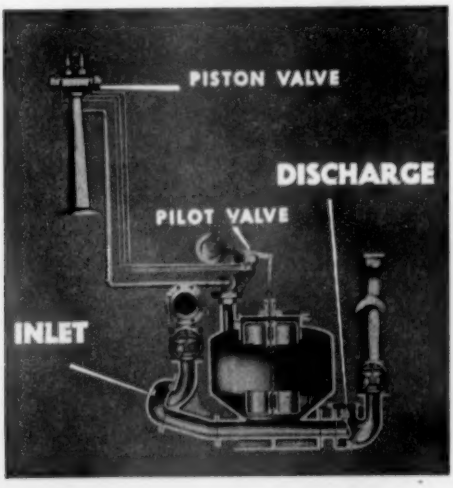

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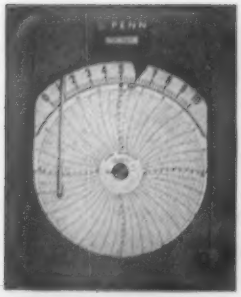

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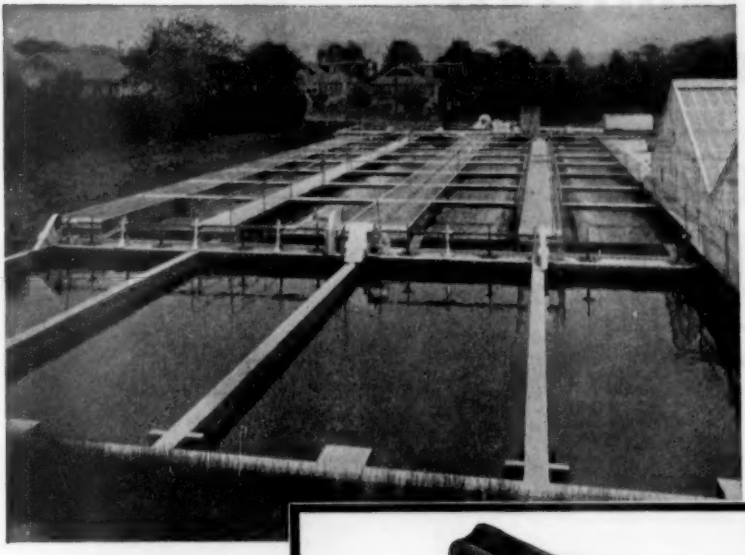

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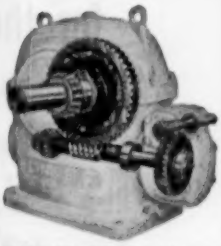

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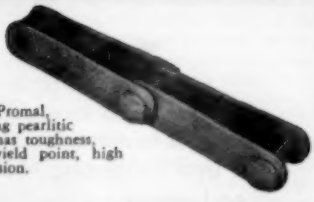

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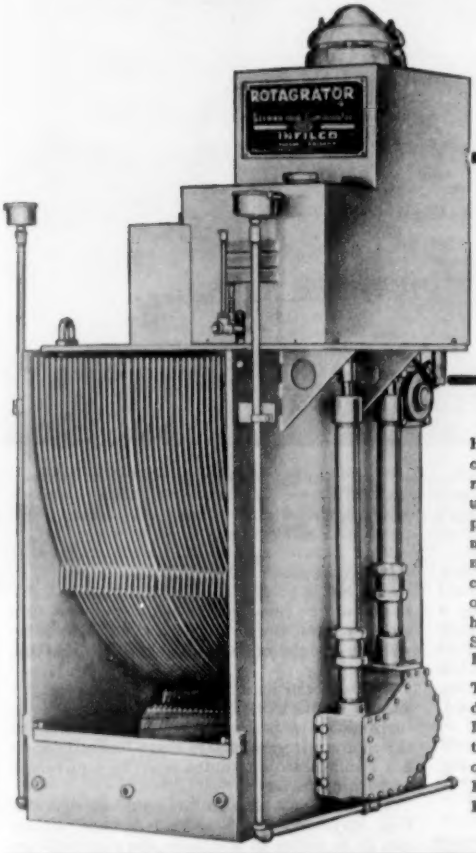

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Southwest	Activated	8	21,000	148,500
Southwest Ext.	Activated	6	21,000	49,500
Edgewater, New Jersey	Pri. Dig.	1	785	150
Fond Du Lac, Wisconsin	Pri. Dig.	1	2,350	1,500
Houston, Texas	Activated	2	12,000	30,400
Lansing, Michigan	Act. Dig. & Garbage	1	6,667	6,780
Los Angeles, California	Act. Dig.	4	22,500	79,500
Recife, Brazil	Pri. Dig.	1	943	1,280
San Diego, California				
#1 Plant	Pri. Dig.	1	3,500	7,500
#2 Plant	Pri. Dig.	1	5,000	13,200
San Francisco, California	Pri. Dig.	3	6,250	36,400
Schenectady, N. Y.	Pri. Dig.	1	3,370	2,970
Sheboygan, Wisconsin	Pri. Dig.	1	3,040	3,080
Stamford, Connecticut	Pri. Dig.	1	3,330	1,780
Washington, D. C.	Pri. Dig. now Act. Dig. later	3	12,000	65,500
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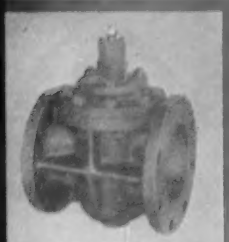

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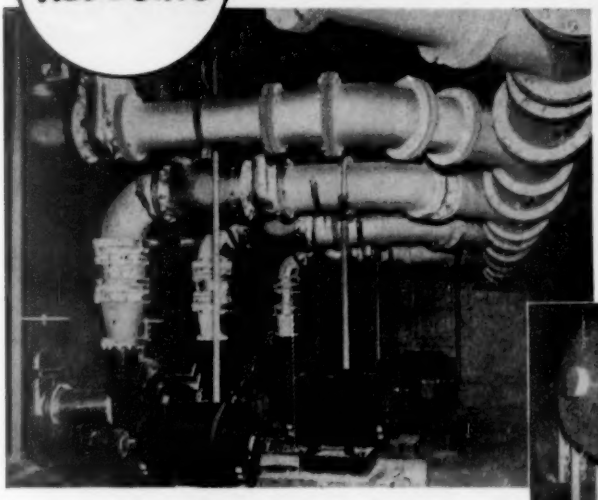

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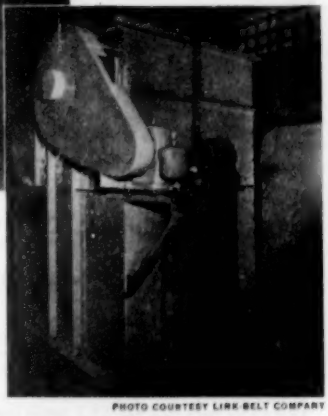

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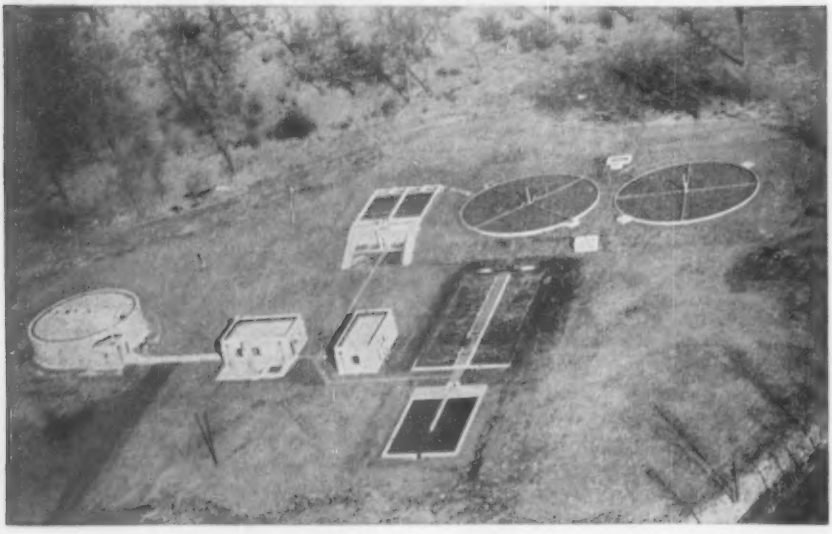
Left, 50' digester with PFT Floating Cover. Top right, 2 filter beds with PFT Rotary Distributors



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SEWAGE AND INDUSTRIAL WASTES

Journal of the Federation of Sewage and Industrial Wastes Associations

Volume 27 **August, 1955** **Number 8**

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Sewage Works

PLANT-SCALE TEST OF A BIOCATALYST ON SLUDGE DIGESTION

By William N. Wells and Ross E. McKinney

Superintendent, Sewage Disposal Plant, San Antonio, Tex., and Assistant Professor of Sanitary Engineering, Massachusetts Institute of Technology, Cambridge, Mass.

In recent years the organic loadings on some sewage treatment plants have exceeded the design factors and have created many operating problems. In an effort to solve the operating problems facing the sewage treatment plant operators, commercial biocatalysts were introduced. For the most part, the biocatalysts were marketed before being thoroughly tested. McKinney (1), in an effort to promote proper understanding of these new materials, discussed the fundamental theory of waste disposal and the relationships which enzymes and bacteria have in the reduction of organic matter. McKinney and Poliakoff (2) could not find any increase in efficiency of activated sludge due to the addition of biocatalysts at 100 times the recommended dosages. Heukelekian and Berger (3) studied the action of pure enzymes, enzyme and bacteria preparations, and yeast, on non-sterile fresh solids, sterile solids, and settled sewage. They found that the materials tested did not increase liquefaction of solids as measured by an increased B.O.D. in the supernatant liquor and neither increased nor decreased the B.O.D. of the settled sewage. These studies were all made on a laboratory scale.

In an effort to obtain information on plant-scale operations, McKinney and Sawyer (4)(5) surveyed the literature and polled the state sanitary engineers to obtain any information reported through their offices. A survey also was made of operations in California by a committee of the California Sewage and Industrial Wastes Association (6). Although reports have been submitted on plant operations, no information has been reported on a controlled plant experiment.

Scum control in the digesters of the San Antonio, Tex., sewage treatment plant presents quite a problem. Because the control of scum is one of the beneficial effects ascribed to the use of biocatalysts by the manufacturers of these materials, it was proposed to test the efficacy of a biocatalyst on scum control and at the same time to check any effect which the biocatalyst might have on digestion.

Each of the 10 open digesters at the San Antonio plant is 75 ft. in diameter, 26 ft. deep at the sidewalls, and has a capacity of 928,000 gal. Soundings indicated that the scum layer was from 12 to 15 ft. thick. Little digestion takes place in the scum layer, so the effective capacity of the digesters is reduced by at least 30 to 40 per cent.

Previous experiences with biocatalysts had been inconclusive. During 1952, 300 lb. of Enzymatic were added to one of the digesters, according to the following schedule: June, 100 lb. were added by mixing with the primary sludge being pumped into the

digester; July, 100 lb. were broadcast over the surface of the scum; and August, 50 lb. were added to the incoming sludge and 50 lb. again broadcast over the scum. No control tests were run, but the scum was not dissipated. No sludge was pumped to the digesters during this period except that to which the Enzymatic had been added.

During August and September 1953, 50 lb. of another biocatalyst, Bionetics, was tried in one of the digesters. Tests run on this digester and on another as a control showed a slightly greater reduction in total solids in the test digester than in the control. A reduction in total solids is one of the beneficial effects claimed by the manufacturer, hence a more extended period of testing was planned. It is the results of this test which are described in this paper.

Procedure

For testing purposes, two digesters were taken out of regular service. The average volumetric loading of the 10 digesters was calculated and the two digesters were loaded at a proportionate rate by pumping the required amount of a mixture of primary sludge and excess activated sludge into the digesters once each week. A base run of seven weeks was made to determine the operating condition of digesters before additions of Bionetics were started. During the eighth week, the addition of Bionetics to one of the digesters was begun—100 lb. the first week, then 20 lb. per week for four weeks, and finally 30 lb. for the balance of the 12-week period. This dosage was recommended by the manufacturer. Finally the digesters were tested for eight weeks after the last addition of the biocatalyst. These periods are referred to as Period I, Period II, and Period III, respectively.

Primary sludge and excess activated sludge were pumped to the digesters from a wet well. The biocatalyst was added to the test digester by mixing it with the sludge in the wet well and then pumping to the digester. To be sure that the control digester did not receive any biocatalyst, sludge was always pumped to it before pumping the mixture to the test digester.

TABLE I.—Scum Characteristics

Depth (ft.)	November 11, 1953		April 6, 1954	
	Total Solids (%)	Vol. Solids (%)	Total Solids (%)	Vol. Solids (%)
(*a*) Control Digester				
3	26.4	67.2	11.7	75.4
6	23.4	65.6	11.6	75.0
9	24.1	62.0	12.1	74.2
12	19.5	62.4	1.45	73.3
(*b*) Test Digester				
3	28.2	76.6	17.8	72.3
6	19.2	80.4	19.9	74.0
9	19.4	65.5	18.4	73.8
12	2.36	67.7	1.74	71.0

As one of the primary points of interest was scum control, two surveys of scum conditions were made, one at the beginning of Period I and one at the end of Period II. The scum was too heavy to sample by conventional methods, but representative samples were obtained by coring.

Since the digesters have no covers, gas production could not be used to evaluate the action of the biocatalyst; instead, observations were made of pH changes and changes in the total and volatile solids of the supernatant liquor and digested sludge of the two digesters. It is believed that any great change in the digestion rate should be reflected in these factors, particularly in the pH and volatile solids.

Evaluation of the operation of the two digesters was also made by means of a solid balance. The pounds of total and volatile solids withdrawn from the digesters were checked

against the pounds of total and volatile solids introduced to the digesters. It should be noted that during the test the digesters were somewhat overloaded. Since there is at least a 30 per cent loss in digestion capacity due to the scum layer, the test digester was loaded at an average rate of 0.071 lb. of volatile solids per cubic foot of digestion capacity per day, while the control was loaded at a 0.078-lb. rate. Since 0.04 lb. of volatile solids per cubic foot per day is considered normal loading, both digesters were more than 75 per cent overloaded.

During Period II the scum in the control digester began to break up and the supernatant withdrawal pipes clogged. To continue additions at a regular rate it was necessary to draw a volume of digested sludge equal to the volume of supernatant liquor which should have been drawn. This same phenomenon took place, to a lesser extent, in the test digester during Period III, necessitating withdrawal of digested sludge several times instead of supernatant liquor.

Frequent observations of temperatures were not made, but several checks showed the supernatant liquor to be about 76° F. during the early part of the test, rising to about 82° F. toward the end of the test period.

Data and Results

Table I shows the condition of the scum to depths of 12 ft. at the beginning of the test and at the end of Period II. No great change had taken place in the scum of the test digester, whereas the solids in the control had decreased by more than 50 per cent. This change in the scum layer of the control is reflected in the poor quality

TABLE II.—Primary Sludge and Excess Activated Sludge to the Control Digester

Date	Volume Added (1,000 gal.)	pH	Total Solids (%)	Volatile Solids (%)	Total Solids (lb.)	Volatile Solids (lb.)
11-24-53	238	—	2.59	77.8	51,200	39,800
12-1-53	285	6.20	3.27	67.6	72,700	52,500
12-8-53	285	6.35	1.77	78.0	42,000	32,800
12-15-53	280	—	1.71	78.0	39,900	32,200
12-22-53	256	6.80	1.73	78.7	36,800	29,000
12-29-53	256	6.32	2.41	77.6	51,500	40,000
1-5-54	259	—	1.75	76.8	37,800	29,000
1-12-54	250	6.20	2.42	75.5	50,400	37,000
1-19-54	280	6.28	3.73	77.2	87,000	67,200
1-26-54	315	6.15	2.53	77.1	66,500	51,300
2-2-54	285	6.72	2.68	75.6	63,500	48,100
2-9-54	321	6.80	3.09	80.7	82,600	66,700
2-16-54	280	6.40	2.39	78.6	55,700	43,800
2-23-54	238	6.05	2.77	78.2	54,900	42,900
3-2-54	274	6.40	1.92	78.7	43,800	34,500
3-9-54	285	6.22	2.09	77.0	49,600	38,200
3-16-54	285	6.20	2.91	80.0	69,000	55,200
3-23-54	288	6.30	2.67	77.4	64,000	49,500
3-30-54	303	6.22	2.41	79.0	60,800	48,000
4-6-54	309	6.30	2.98	78.4	76,700	60,200
4-13-54	294	6.32	3.44	88.0	84,200	74,200
4-20-54	291	6.20	2.40	76.3	58,200	44,400
4-27-54	271	6.05	2.11	74.5	47,700	35,500
5-4-54	285	6.22	1.94	74.1	46,200	34,200
5-11-54	268	5.90	2.86	75.0	64,000	48,000
5-18-54	256	6.23	2.39	74.4	51,000	37,900
5-25-54	333	6.27	2.52	74.8	70,000	52,400
6-1-54	277	6.15	2.53	76.0	58,400	44,400

TABLE III.—Primary Sludge and Excess Activated Sludge to the Test Digester

Date	Volume Added (1,000 gal.)	Bionetics (lb.)	pH	Total Solids (%)	Volatile Solids (%)	Total Solids (lb.)	Volatile Solids (lb.)
11-24-53	274	—	—	2.59	77.8	59,200	46,000
12-1-53	288	—	6.26	3.27	67.6	78,500	53,000
12-8-53	280	—	6.35	1.77	78.0	41,400	32,200
12-15-53	280	—	—	1.71	78.0	39,900	31,200
12-22-53	291	—	6.80	1.73	78.7	42,000	33,000
12-29-53	274	—	—	2.41	77.6	55,000	42,700
1-5-54	318	—	6.32	1.75	76.8	46,400	35,600
1-12-54	262	100	—	2.77	80.0	60,500	48,400
1-19-54	277	20	6.16	2.51	77.2	58,000	44,700
1-26-54	256	20	6.98	1.90	76.8	40,500	31,100
2-2-54	274	20	6.50	2.20	76.5	50,300	38,400
2-9-54	294	20	6.30	2.20	78.2	53,900	42,200
2-16-54	268	30	6.12	2.75	78.5	61,400	48,200
2-23-54	274	30	6.35	2.40	79.0	55,700	43,300
3-2-54	244	30	6.35	3.38	80.0	68,600	55,000
3-9-54	285	30	6.10	2.33	78.5	55,400	43,400
3-16-54	232	30	6.20	2.96	79.2	57,200	45,300
3-23-54	303	30	6.32	2.51	77.2	63,400	48,900
3-30-54	208	30	6.30	2.53	75.5	43,800	33,100
4-6-54	214	—	6.20	1.78	74.6	31,800	23,900
4-13-54	232	—	6.25	2.36	76.0	45,600	34,600
4-20-54	318	—	6.28	2.58	76.7	68,200	52,400
4-27-54	226	—	6.00	2.32	75.2	43,700	32,900
5-4-54	262	—	6.40	2.29	75.5	50,000	37,800
5-11-54	268	—	6.30	5.39	58.0	120,000	69,700
5-18-54	250	—	6.10	2.63	76.2	54,800	41,700
5-25-54	274	—	6.60	1.65	73.6	38,400	28,200
6-1-54	274	—	5.87	3.22	75.5	73,500	55,500

of the supernatant liquor during Period II.

Tables II and III give the amounts and characteristics of the sludge added to the two digesters, as well as the quantity of biocatalyst added to the test digester. Tables IV and V show the condition of the supernatant liquor and the digested sludge drawn from the digesters.

During Period I (before the biocatalyst addition was started) the pH of the supernatant liquor averaged 6.93 for the test digester and 6.98 for the control, indicating only fair digestion. (A value near 7.4 would have indicated good digestion.) During this period the volatile solids in the supernatant liquor averaged 61.5 per cent for the test digester and 62.4 per cent for the control.

During Period II, the supernatant liquor of the test digester averaged pH 7.01 and of the control pH 6.82. The volatile solids of the supernatant liquor averaged 66.0 per cent for the test digester and 67.6 per cent for the control. The pH value of 7.01 indicates slightly better digestion in the test digester, but the high volatile solids indicates poorer digestion.

During the past 20 years the volatile solids in the digested sludge at the San Antonio plant have averaged 60.0 per cent. During this test the digested sludge from the control digester averaged 65.5, 67.0, and 64.4 per cent for Periods I, II, and III, respectively, whereas the test digester averaged 62.4, 65.5, and 61.1 for the three periods. All of these values fall short of the 20-year average, indicating poorer than average digestion in both the test and control digesters.

Analysis of Results

Two of the major problems in plant-scale experiments are the obtaining of suitable samples for analyses and the proper interpretation of the data. In this study the analytical phase did not present as great a problem as did the interpretation of the data. Although the digesters were operated over a 6-month period, the amount of data taken during each of the test periods was limited. It was not possible to analyze the data on the basis of the sludge added and the sludge removed each week, since the sludge removed had little relationship to the sludge added. Averages over each of the three test periods meant little because of the shortness of each period and the length of sludge detention in the digesters. If no mixing of the digester contents had occurred, the detention period in the digesters would have ranged between two and three weeks. Actually, some mixing did take place and the average detention period in the digesters was less than two weeks. Figures 1 and 2 illustrate the effect of digester detention period on the volatile solids. These figures contain plots of the volatile solids added each week and the volatile solids removed. The difference between the two lines represents the quantity of volatile solids digested in most cases, although there were a few instances where more organic matter was removed than added. These zones, indicated as "excess," occurred during Period II in the control digester and during Periods II and III in the test

TABLE IV.—Supernatant Liquor and Digested Sludge from the Control Digester

Date	Volume (1,000 gal.)		Supernatant			Digested Sludge			Solids Out (lb.)	
	Supnt.	Sludge	pH	Solids (%)	Vol. Sol. (%)	pH	Solids (%)	Vol. Sol. (%)	Tot. Sol.	Vol. Sol.
11-23-53	178	36	7.00	0.66	61.5	6.80	2.43	65.9	17,270	10,930
11-30-53	247	39	—	1.48	65.8	6.85	2.60	67.0	39,050	25,760
12-7-53	247	36	7.00	0.93	62.9	6.70	3.29	63.0	29,010	18,200
12-14-53	250	36	6.95	0.25	56.1	6.72	3.55	63.3	15,850	9,650
12-21-53	250	36	7.00	1.17	63.4	6.82	3.25	63.8	34,130	21,700
12-28-53	250	36	7.00	1.11	64.5	6.51	3.32	64.1	32,050	21,280
1-4-54	250	36	7.00	1.06	65.4	6.65	4.00	67.3	34,100	22,350
1-11-54	250	36	6.90	0.34	59.5	6.60	3.69	78.7	18,900	11,820
1-18-54	250	42	7.20	1.43	66.4	6.88	3.91	67.7	43,480	29,010
1-25-54	315	36	6.70	1.91	69.4	6.51	4.47	69.5	63,600	54,100
2-1-54	250	36	6.65	0.86	65.2	6.60	4.22	69.3	30,550	20,450
2-8-54	256	36	6.75	2.82	67.8	6.55	6.05	68.9	78,400	53,300
2-15-54	250	36	6.65	0.70	71.1	6.30	4.95	68.8	29,400	20,580
2-22-54	250	36	6.72	2.93	67.2	6.68	5.04	67.8	76,100	51,250
3-1-54	250	36	6.50	2.77	66.9	6.90	5.12	67.3	73,100	49,500
3-8-54	250	36	6.83	2.91	68.0	6.75	5.60	65.0	77,400	52,100
3-15-54	238	42	7.00	1.38	67.3	6.80	6.13	64.8	48,800	32,300
3-22-54	250	39	7.08	1.26	68.8	6.65	5.60	68.4	44,400	30,500
3-29-54	250	36	6.72	2.34	69.5	6.70	4.01	64.6	60,700	41,600
4-5-54	256	36	7.10	1.59	65.8	6.74	3.68	64.8	42,900	28,200
4-12-54	244	36	6.88	2.06	67.4	6.80	3.53	66.0	52,500	35,200
4-19-54	250	62	6.75	0.34	65.4	6.70	3.11	68.0	23,100	14,500
4-26-54	250	36	6.98	2.19	67.6	6.70	2.81	67.8	62,100	41,900
5-3-54	250	36	7.15	0.22	51.2	6.58	3.90	62.0	16,300	9,590
5-10-54	285	36	6.80	0.31	58.9	6.50	4.35	64.0	17,710	10,950
5-17-54	232	36	7.00	0.63	62.3	6.80	3.23	62.7	21,900	13,670
5-24-54	291	36	7.25	1.11	62.8	6.90	2.80	62.2	35,400	22,130
5-31-54	253	36	7.20	0.75	63.7	6.90	2.94	63.0	24,600	15,660

TABLE V.—Supernatant Liquor and Digested Sludge from the Test Digester

Date	Volume (1,000 gal.)		Supernatant			Digested Sludge			Solids Out (lb.)	
	Supnt.	Sludge	pH	Solids (%)	Vol. Sol. (%)	pH	Solids (%)	Vol. Sol. (%)	Tot. Sol.	Vol. Sol.
11-23-53	250	36	6.90	1.19	62.8	6.85	4.98	61.2	39,700	24,720
11-30-53	241	42	6.91	0.78	63.9	6.82	5.04	63.2	33,300	21,170
12-7-53	247	39	7.00	0.22	53.7	6.72	4.02	61.5	27,550	10,430
12-14-53	250	36	7.01	0.21	54.0	6.78	4.10	61.8	16,680	9,960
12-21-53	280	36	6.80	0.52	60.0	7.00	3.90	62.6	23,840	14,600
12-28-53	253	36	7.00	1.48	72.0	6.55	3.50	61.6	41,700	28,860
1-4-54	250	42	6.90	1.44	63.6	6.75	3.60	63.9	42,600	27,150
1-11-54	262	36	6.90	0.76	62.3	6.70	3.17	64.0	26,140	16,420
1-18-54	250	39	7.00	1.63	65.5	6.80	2.65	65.5	42,600	27,820
1-25-54	250	36	6.85	1.97	66.2	6.78	2.85	65.5	49,650	32,700
2-1-54	238	36	6.92	0.28	56.7	6.80	3.44	64.8	15,850	9,820
2-8-54	253	42	6.85	0.67	61.5	6.75	3.73	65.3	27,200	17,200
2-15-54	262	36	6.95	1.56	66.5	6.80	4.18	66.6	46,500	30,950
2-22-54	297	36	7.10	0.92	66.0	6.86	4.33	66.4	35,700	23,600
3-1-54	250	36	7.00	0.67	66.3	6.80	4.48	66.8	27,500	18,200
3-8-54	250	36	6.88	0.38	69.0	6.84	4.51	64.8	21,400	14,800
3-15-54	202	36	7.00	0.46	69.3	6.70	4.30	65.2	20,650	13,800
3-22-54	256	42	7.05	0.44	69.7	6.83	4.59	65.9	25,370	17,340
3-29-54	214	36	7.48	0.37	63.7	6.90	3.57	65.3	17,300	11,220
4-5-54	208	36	7.00	2.73	72.2	6.84	3.07	64.6	56,600	40,150
4-12-54	232	36	6.95	0.77	70.4	6.88	3.08	64.2	24,150	16,420
4-19-54	250	71	7.10	1.32	68.0	6.80	3.12	63.8	45,900	30,500
4-26-54	178	36	7.12	4.64	75.0	6.85	2.84	64.1	77,300	57,100
5-3-54	238	36	7.10	2.18	73.5	6.88	2.55	62.4	50,850	36,570
5-10-54	250	36	7.20	0.86	62.3	6.72	2.68	63.5	25,930	16,600
5-17-54	208	36	6.90	2.56	63.7	6.85	4.90	54.1	59,100	36,150
5-24-54	250	36	6.96	0.86	60.6	6.90	3.80	56.4	29,300	17,250
5-31-54	250	36	7.15	1.45	60.5	7.10	3.02	60.5	39,250	23,740

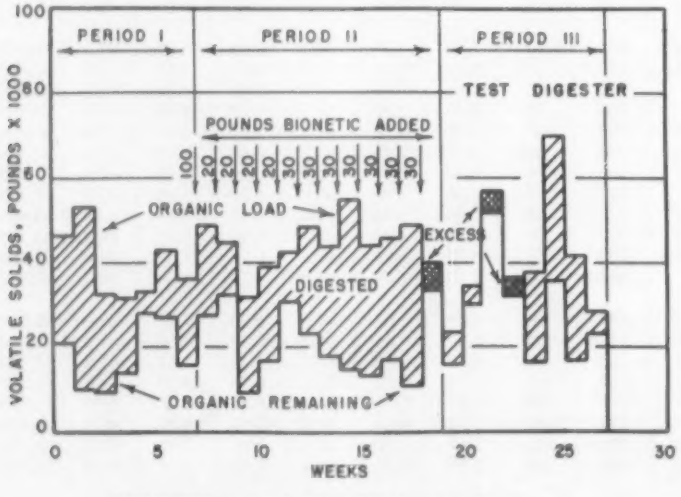

FIGURE 1.—Volatile solids in test digester.

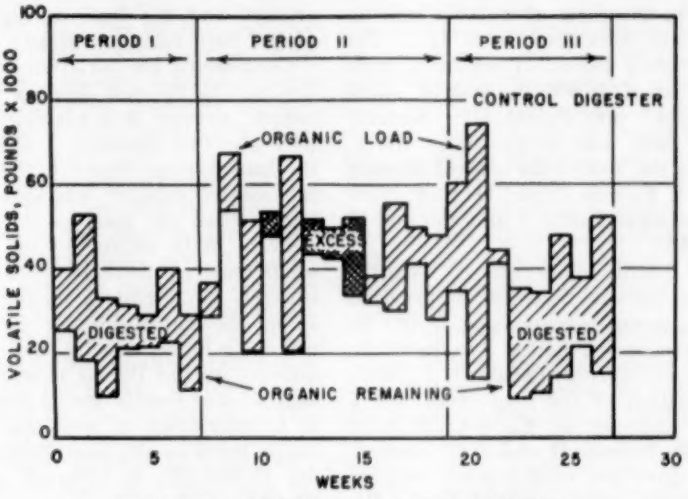

FIGURE 2.—Volatile solids in control digester.

digester. The "excess" zones appeared after sudden changes in loading. It can be seen from Figures 1 and 2 that a sudden increase in organic loading was reflected in the sludge drawn off from one to two weeks later.

To analyze properly the data obtained, a statistical analysis was made correcting the organic balance for a detention lag of one week. Statistical analysis of the data was made according to the small-sample theory, the "*t*" test (7).

Since reduction in volatile solids is the prime function of any digestion unit, the statistical analysis was made on the volatile solids data. The mean for each period and the standard deviations are shown in Table VI for the volatile solids balance. It can be seen that the load on the control digester increased considerably between Periods I and II. The increased load

TABLE VI.—Loadings and Removals

Period	Item	Volatile Solids (lb./week)		Volatile Solids (lb./day/cu. ft.)	
		Control Digester	Test Digester	Control Digester	Test Digester
I	In	36,300 ± 8,530	39,100 ± 8,340	0.070	0.075
	Out	18,700 ± 5,900	18,400 ± 7,560		
	Removed	17,600	20,700		
	% Removal	48.5	53.0		
II	In	48,500 ± 11,200	43,500 ± 6,600	0.080	0.072
	Out	38,600 ± 13,100	21,500 ± 9,530		
	Removed	9,900	22,000		
	% Removal	20.4	50.0		
III	In	48,400 ± 12,000	40,200 ± 14,700	0.079	0.066
	Out	20,500 ± 11,900	29,300 ± 7,290		
	Removed	27,900	10,900		
	% Removal	57.8	27.1		

came in the form of a shock load on the ninth week (see Table II). The load during Period II continued high (a mean of 48,500 lb. volatile solids per week) into Period III. Statistically, there was no significant difference in the load to the control digester between Periods II and III; but there was between Period I and Periods II and III.

The volatile solids removed from the control digester reflected the overload with a mean increase from 18,700 lb. per week during Period I to 38,600 lb. per week during Period II. With stabilization of the load there was a steady increase in digester efficiency through Periods II and III. Statistically, there was no difference between the volatile solids removed during Periods I and III; but there was a significant difference between the amount removed in Period II and Periods I and III.

The organic load on the test digester did not undergo as abrupt a change as did the control digester between Periods I and II; but the change was statistically significant. The load during Period III did not vary significantly from either Periods I or II. Thus, it can be seen that the load on the test digester was more uniform than on the control digester. This also is shown in Figure 1, where the increase in load in the test digester was much more gradual than in the control digester. There was considerable variation in loading during Period III in the test digester, but the experiment did not run long enough to fully evaluate the effect of the shock load on the 25th week.

The test digester showed no significant difference in the volatile solids removed from the digester during Periods I and II, but did show a significant difference between Periods I and II and Period III. There is no apparent explanation of the sudden increase in volatile solids removed, because the load on the digester was actually decreased rather than increased and the load during Period II had been relatively steady.

Considering the variation in organic loadings to the test digester and the control digester, it is not easy to compare the two digesters. Aside from the load during Period I, the load to the control digester was significantly higher than the load on the test digester. With regard to the volatile solids removed, there was no difference between the digesters during Period I; but the control digester showed significantly higher results than the test digester during Period II and significantly lower results during Period III. It is interesting to note that significantly lower results were obtained during Period III in spite of a higher loading.

Discussion

It would seem that if Bionetics aids digestion, its addition to a poorly operating or overloaded digester should cause changes in a number of variables. The pH should increase, the total solids in the supernatant liquor should decrease and, most important, the percentage of volatile solids in the digested sludge and the supernatant should decrease. These changes should be noticeable in the supernatant liquor sooner than in the digested sludge because of the more rapid displacement of the supernatant liquor and because the biocatalyst would have a higher concentration in this region of the digester.

The problem studied is a common one to sewage plant operators. The permanent solution to the problem of unheated uncovered digesters with thick scum layers is the modification of these units to satisfy the modern design criteria of external heat exchangers, covers to prevent loss of heat and to recover gas for heating, and mixing of the contents to insure proper contact between the microorganisms and the organic matter. The temporary solution of the problem through the use of biocatalysts would have been a boon to the sewage treatment field,

but it was found through this plant-scale study that the addition of one biocatalyst did not aid digestion. The scum layer was not changed in the test digester. Thus, Bionetics was not the solution to the problem at San Antonio.

As pointed out by previous investigations, the biocatalysts can function as claimed by the manufacturers only if the microorganisms normally present in a properly operating digester are absent and are not being added in the raw sewage and the environmental conditions in the digester are satisfactory for growth of the organisms added by the biocatalyst. The digesters at San Antonio were not under the usual adverse environmental conditions of low pH. But even in the presence of proper environmental conditions the addition of selected microorganisms in the form of a biocatalyst failed to bring about additional stabilization of the organic matter. The volatile solids content in the digested sludge ranged from 5 to 10 per cent above that obtained in good digested sludge having similar volatile solids in the raw sludge and was approximately 5 per cent higher than average results obtained over the past 20 years. The higher volatile solids content was due in part to the decreased time the solids actually remained in the tank. Based on the operating data presented in this report, there is little doubt that the digesters are performing at their optimum efficiency under the present operating conditions. Removal of the present scum layer and prevention of its recurrence would provide sufficient capacity to improve operation effectively until the proper structural changes can be made to permit maximum operation under present practice. Removal of the scum layer will have to be done by mechanical means, since both the biocatalyst used in this study, and the one used in a previous study failed to reduce the scum layer.

Summary and Conclusions

1. A 28-week study was made of two open digesters. During 12 weeks of this period Bionetics was added to one of the digesters at a rate recommended by the manufacturer.

2. No significant reduction in scum was noted in the digester to which the biocatalyst was added.

3. No significant changes were noted in the pH, total solids, and volatile solids of the supernatant liquor or digested sludge of the test digester. A solids balance failed to reveal any marked improvement in digestion.

4. It is believed that the experimental data presented support the *a priori* reasoning of Heukelekian and Berger that the addition of bacterial cultures and enzymes to sewage solids cannot result in material improvement in digestion.

Acknowledgment

The Bionetics used in this test was furnished by the Reliance Chemical Company of Houston, Tex.

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THE CINCINNATI SEWAGE DISPOSAL PROGRAM *

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Although there are many phases of the Cincinnati sewage disposal program, this paper deals primarily with the financing and industrial waste ordinance phases. It is appropriate, however, to discuss briefly the history of the program and to touch briefly on present construction progress.

As early as 1912 an engineering report on a sewerage plan for Cincinnati, Ohio, pointed out the problems now facing that city and in process of solution.

That report also anticipated the then future necessity for treating the sewage of the city and its surrounding municipalities, which under the present program include 23 participating political subdivisions (Figure 1).

By 1938, due to the increase in pollution of the Ohio River, the necessity of treating sewage became a reality. In late summer of that year, therefore, Cincinnati's council passed enabling legislation directing the city administration to conduct a survey to formulate a plan for the disposal of sewage. Consulting engineers were retained to make this survey, and in July 1941 a report on a plan for the disposal of sewage was submitted.

Basically this report outlined a construction program estimated to require seven years and cost $19,500,000. It called for the immediate construction of two sewage treatment plants, four pumping stations, and four intercepting sewers, with two additional sewage treatment plants with the necessary pumping stations and intercepting sewers to be built at a future date. The plants were to be built for primary treatment only. The City Council accepted the report and set up the program for $17,000,000, delaying the lower river plants until a future date.

The start of the program was the drawing up of plans and specifications for the Little Miami Sewage Works, and contracts were to be let in 1941. Due to World War II, the plans were shelved and it was not until 1945 that disposal of sewage again was considered in Cincinnati.

At that time a committee of engineers and city officials throughout the county was formed to establish a method to finance the sewage disposal program. It was finally agreed that Cincinnati would administer the program and 25-year contracts would be signed by the surrounding communities and Hamilton County. This was not unusual, because the contributary sewage from the outlying communities flowed through Cincinnati to the Ohio River. Therefore, the Cincinnati metropolitan sewage disposal program is administered, operated and maintained by the City of Cincinnati, with all 24 participating communities paying the same rate per 100 cu. ft. of sewage treated.

Collection of the monies began in July 1948, and the first plant was placed under construction in January 1951. By that time, nearly $4,500,000 had been collected in advance and it was possible to obtain a very fine interest rate of 1⅞ per cent for the $5,000,000 worth of bonds sold in 1951. Again war, in Korea, slowed down construction.

* Presented at 27th Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; Cincinnati, Ohio; Oct. 11–14, 1954.

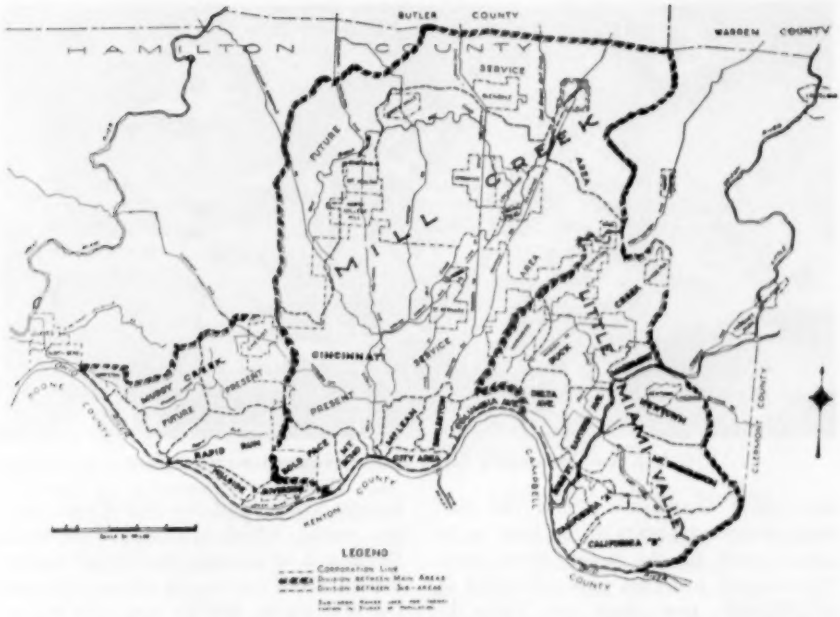

FIGURE 1.—Metropolitan area of Cincinnati, Ohio, included in sewerage studies.

In October 1953 the first sewage treatment plant, known as the Little Miami sewage works, was placed in operation. This plant (Figure 3), serving an area of 27 sq. mi. with a population of 120,000 people in the eastern section of the city, was designed for a maximum flow of 29 m.g.d. based on 240 p.p.m. B.O.D. and 270 p.p.m. suspended solids. The plant and its appurtenances cost a little more than $5,500,000.

In the meantime, the existing rate structure was shown to be inadequate to support the entire sewage disposal program, due to a 176 per cent increase in construction costs from 1941 and increased treatment necessary because of the tentative standards as set forth by the Ohio River Valley Water

FIGURE 2.—Location of interceptors and treatment plants.

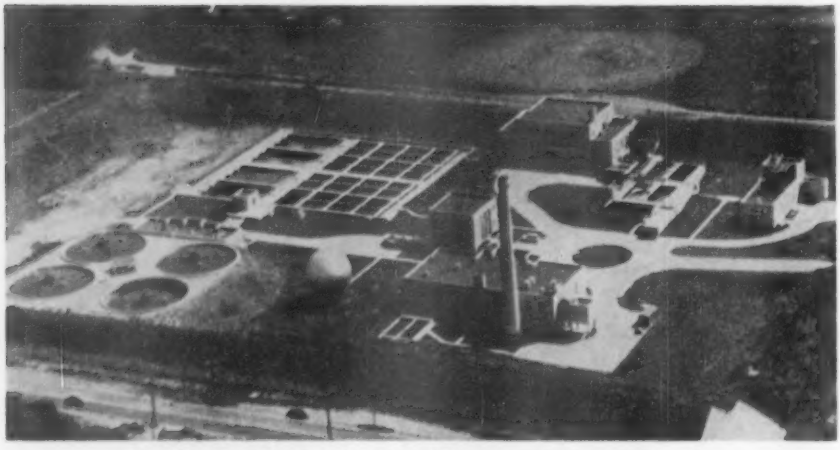

FIGURE 3.—Cincinnati's Little Miami sewage treatment plant.

Sanitation Commission, and the fact that treatment plants would have to be constructed in the lower river area. The revised program was estimated at $47,000,000; new rates (see Table I) were placed in effect in February 1953 and revenues are now being collected at the rate of approximately $3,000,000 a year on the sewerage service charge.

The sewerage service charge is collected by the water works departments of the cities serving the 24 communities in the agreement. The charge is simply added as a separate item on the water bill. Billing expenses up to 3 per cent of the collection are allowed.

The Program

The program consists primarily of the previously mentioned Little Miami sewage works, and the Mill Creek sewage works, which is designed to treat 120 m.g.d. of sewage containing highly concentrated industrial wastes containing 400 p.p.m. B.O.D. and 500 p.p.m. suspended solids. The Mill Creek plant is to be a modified primary plant consisting of primary treatment with the additional facilities for flocculation and chemical treatment during the low flows in the Ohio River in order to maintain 4 p.p.m. of dissolved oxygen at the bottom of the oxygen sag curve below Cincinnati in the Ohio River.

TABLE I.—Relationship Between Sewer Service Charge Rates Before and After February 1953

Water Consumption (100 cu. ft. per mo.)	Rate ($/100 cu. ft.)	
	Before Feb., 1953	After Feb., 1953
from 0–600	0.06	0.08
next 4,400	0.054	0.08
next 5,000	0.048	0.072
next 20,000	0.036	0.072
over 30,000	0.03	0.056

The $22,000,000 construction program of the Mill Creek sewage works is being broken down into contracts of from $2,000,000 to $5,000,000 each.

In October 1954 construction was underway on 12 110-ft. diameter digesters 32 ft. deep. Contracts for the administration building and the power-service building were being let, and $3,000,000 of outfall and intercepting sewers were under construction.

A new report has been made whereby it is hoped to be able to combine the lower river plants into one plant. Although the construction costs of this plant with its approximately 9 mi. of intercepting sewers will be higher than the construction cost of two small sewage treatment plants

with deleting part of the intercepting sewers, the lower operating and maintenance cost of the single plant over a period of 25 years will more than justify the use of one plant.

Financially the sewage disposal program at the present time is in very good shape. As of July 1, 1954, $22,500,000 worth of bonds had been issued, but the reserve fund for payment of bonds amounted to $11,910,626 and there was $160,215 in the replacement capitalization equipment reserve. This seems like a large reserve for bond payments, but in 1956 more will be paid out in bond principal and interest payments, together with operation and maintenance costs, than is received in revenue. This will continue until 1976, when the reserve fund will begin reducing until there is only about $200,000 in reserve, a very narrow margin.

Organization

Of interest is the sewage disposal program's organization chart (Figure 4), which, of course, is still flexible. It is noted that there is an Office Administration Section, a Sewerage Service Charge and Industrial Waste Section, and an Operating and Maintenance Engineering Section. This last section includes the planning design, stream pollution abatement, engineering, janitorial, and maintenance groups, as well as the power supply group for the Mill Creek sewage works. Each treatment plant, of course, has its operation, laboratory, and maintenance groups, plus any special groups required in the particular plant.

In October 1954, 81 of the 94 approved positions were filled. These do not include personnel for the Mill Creek sewage works, or the mechanical, electrical, civil or janitorial sections of the operating and maintenance engineering group. The total anticipated personnel will be approximately 225.

Industrial Waste Section

An Industrial Waste Ordinance (No. 25–1953) was passed on January 21, 1953, by the City Council. The authorizing paragraph reads as follows:

"Authorizing and directing the City Manager to make and enforce Rules and Regulations governing the discharge of sewage, industrial wastes and other matters into the Cincinnati Metropolitan Sewage System, establishing rates of surcharge and defining terms."

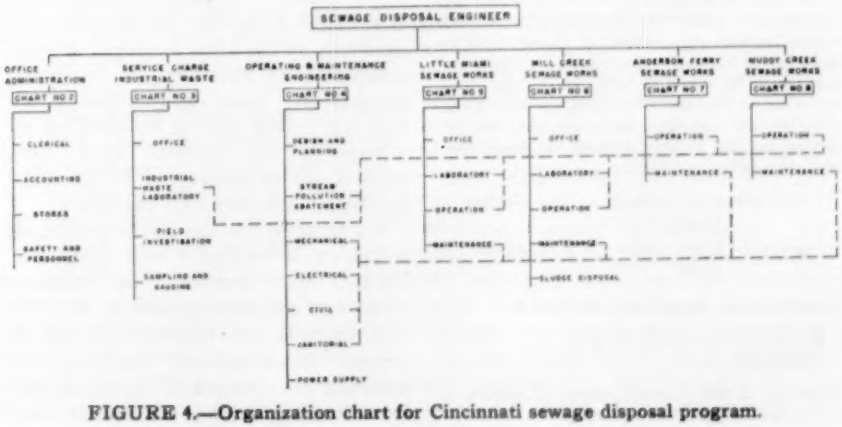

FIGURE 4.—Organization chart for Cincinnati sewage disposal program.

The ordinance basically defines terms and establishes the limits of "normal" sewage to the City of Cincinnati as 240 p.p.m. B.O.D. and 300 p.p.m. suspended solids. It also provides that a surcharge shall be placed upon industries for any wastes above normal sewage strength so that the additional cost of building a sewage treatment plant for the City of Cincinnati over and above what can be considered normal would be paid for by industry rather than to have each industry provide pre-treatment facilities and bring its sewage within the range of normal sewage. A formula sets forth a basis of charge of two constituents, suspended solids and B.O.D. It gives credit for percentage of treatment provided and is devised in such a way that one can readily convert the p.p.m. of suspended solids and B.O.D. back to cubic feet of flow, which is a base unit of charge and is recorded on cards for direct machine billing.

The industrial waste surcharge formula is set forth as follows:

The basis of the surcharge shall be determined on either or both, of two constituents of the water or wastes:

(a) Total suspended solids, and
(b) B.O.D., 5 days at 20 degrees Centigrade and as herein provided.

When either or both the total suspended solids and B.O.D. of a water or waste accepted for admission to the city sewage works exceeds the values of these constituents for "Normal" sewage, the excess concentration in either or both, as the case may be, shall be evaluated volumetrically in terms of "Normal" sewage and be subject to surcharge on the volume derived in accordance with the following formula:

$$Sv = \frac{(Sw\text{-}2500) \times 0.65}{2500} \times F \times 133{,}690$$

$$\text{plus } \frac{(Bw\text{-}2000) \times 0.65}{2{,}000} \times F \times 133{,}690$$

which reduced to its simplest form is

$$Sv = F\,[\,(Sw\text{-}2500)\ 35 \text{ plus } (Bw\text{-}2000)\ 43\ ].$$

where Sv is the derived volume of wastes in cubic feet subject to surcharge.

Sw—the pounds per million gallons of suspended solids in the wastes as discharged.

2,500—the pounds per million gallons of suspended solids in the "Normal" sewage.

Bw—the pounds per million gallons of B.O.D., in the wastes as discharged.

2,000—the pounds per million gallons of B.O.D. in "Normal" sewage.

0.65—Factor allowance for 65% degree of purification.

(Present B.O.D. requirement for Cincinnati Pool established by Ohio River Valley Water Sanitation Commission).

F—the flow expressed in million gallons of the wastes as discharged.

133,690—Factor to convert million gallons to cubic feet.

The equivalent volume of "Normal" sewage as derived from the excess above the normal strength of any water and wastes shall be subject to a surcharge for the volume of equivalent "Normal" sewage as computed from the formula, at a flat rate of three (3) cents for each 100 cubic feet, as above computed.

Disregarding the formula, the rate per pound of B.O.D. over normal sewage is $0.0129 and the rate per pound of suspended solids over normal sewage is $0.0105. The ordinance also provides for the City Manager to make and enforce rules and regulations, establishing the type and characteristics of sewage and industrial wastes, and other matter not admissible to the Cincinnati metropolitan sewage system. It defines the types and strength characteristics of sewage and industrial wastes admissible to the system after pre-treatment. It provides for a board of arbitration in case the findings and decisions of the City Manager are not acceptable by industry. It should be pointed out, however, this last provision has never had to be used as all differences of opinion have been worked out in conference to the satisfaction of industry and the city.

An unusual feature of the ordinance is known is Section 6 and Section 7. Under these sections, an industry could sign a special agreement with the city wherein the industry agreed to provide pre-treatment facilities for lowering the strength of its wastes and for removing wastes considered non-

admissible to the sewers, said facilities to be in operation 12 months from the date of the start of the collection of sewerage surcharge. The agreement stipulated that if an industry fulfilled these requirements, said industry would be refunded the difference between what it had been paying under the sewerage surcharge and what it would have paid if the pre-treatment facilities had been in operation for the previous 12 months. Some 26 companies took advantage of this agreement program and at the present time approximately $89,480 has been refunded to five companies. Additional charges of $146,000 have been made to companies whose final analyses made by the city forces showed the charge, based on the company's original analyses, were too low.

The Ordinance is short, primarily defining what industrial waste is, a method of collection, a method of arbitration, and a method of recapturing money spent for pre-treatment facilities. The one important part is that it does give the City Manager the right to set forth rules and regulations. The primary reason for a short concise ordinance with the right to make rules and regulations, is that it is a known fact that it's much easier to make rules and regulations than to try to amend an ordinance through any council. Any amendments to the Rules and Regulations are carefully analyzed by the city's attorney before they are signed by the City Manager and put into effect.

The Rules and Regulations establish a uniform procedure in the setting up of the sewerage surcharge, and maintain equity in the billing throughout the metropolitan area. Under Section 3 of the Rules and Regulations, the prohibitions and non-admissible wastes are listed. It is to be noted that approximately 85 per cent of the prohibitions listed under Section 3 have been contained in the city's Building Code for a great many years. This is the first time, however, that they have all been brought together under one common heading, so that industry can actually see the prohibitions, although lawyers say that ignorance of the fact is not admissible under the law. The second interesting portion of the Rules and Regulations, as far as prohibitions to the sewers, is that there is no limit on the metal concentrations as they come from any particular industry, when its metal strength could be lost in the total flow coming to the sewage treatment works. Instead, it is stated as follows:

"That materials such as copper, zinc, chromium and similar toxic substance shall be limited to the following average quantities in the sewage as it arrives at the sewage treatment plant, and at no time shall the daily concentration at the sewage treatment plant exceed three times the average concentration:

Iron, as Fe	15 p.p.m.
Chromium, as Cr (hexavalent)	5 p.p.m.
Copper, as Cu	3 p.p.m.
Zinc, as Zn	2 p.p.m.
Chlorine demand	30 p.p.m.

Contributions from individual establishments are subject to control in volume and concentration by the City Manager. Metals are not anticipated in concentrations larger than stated. However, the office has record sheets (Figure 5) on all industries, listing their contributions of the various metals. These records make it possible to determine the various industries contributing that particular metal, and to talk to them about reducing their particular wastes, if necessary.

The prohibitions otherwise are for the protection of the sewers and those who are working in the sewers. To that extent, it should be noted that the industrial waste surveys have located some acid conditions that have damaged the city sewers. Reports of acid conditions within the city limits are directed to the Highway Maintenance Division. This agency inspects

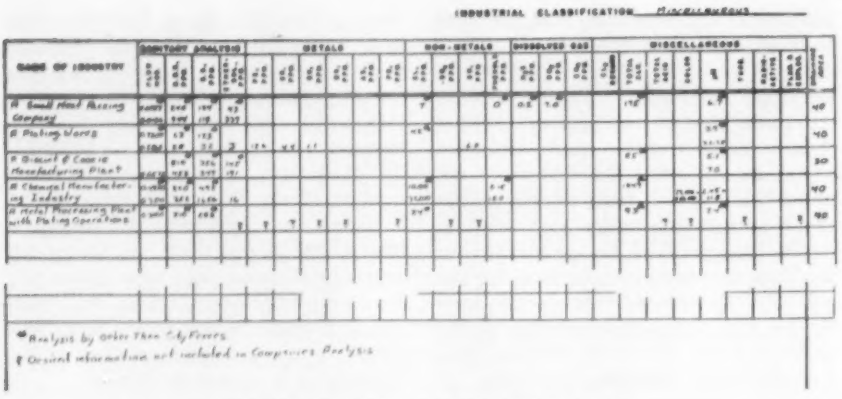

FIGURE 5.—Industrial classification form.

the sewers for extent of damage and prepares an estimate of the cost of repair or replacement to return the conduit to its original service. The industry is then called in for conference and is informed of the extent of damages to the conduits, the costs of repair or replacement, and that the city holds them responsible for payment.

To date more than $135,000 has been collected from various industries for damage done to the city sewers without going to court. The Highway Maintenance Department has these monies in a special fund, which can only be used for repairing or replacement of the damaged sewers. This procedure has made industry cognizant of the fact that when they discharge deleterious materials into a sewer and damage the conduits, they are held responsible and will be expected to pay for same. Acid conditions in the other communities are directed to their attention.

Gaging, Sampling and Laboratory Operations

Setting up the procedure for the gaging, sampling and laboratory procedures, in order to adequately make a complete survey of the industry in the metropolitan area, has been a tremendous job. Some idea of the volume of work that is expended to adequately maintain, police, and administer the industrial waste ordinance may be obtained from the following.

The first step taken was to compile a list of industries by type of waste. The sources of the original data were the "Book of Industries" of the Chamber of Commerce, the classified section of the local telephone book, the descriptions of water company connections, and personal investigation. Preliminary questionnaires seeking general information as to the name of the business, address, operation, hours of operation, number of employees, water supply, and nature of the waste, were mailed to more than 1,900 companies.

Of the original 1,900 mailed, 1,300 replies were received immediately and an additional 460 were received after three reminder letters; that is, 1,760 questionnaires were answered, or 97 per cent of the companies replied. Of the replies received, 902 indicated no further action was necessary and were placed in a closed file. Some additional companies were picked up and a more complete questionnaire asking for a complete analysis of the wastes was sent out to 931. Again, after six reminder letters, 879 replied. As of July 1, 1953, only 30 companies had given complete analyses of their

TABLE II.—Types and Numbers of Industries Subject to Sewerage Surcharge

Type	Number
Laundry	62
Meat packing	59
Food products	28
Metal processing	28
Dairy products	27
Chemical	18
Lithography	13
Brewery and distillery	6
Textiles	5
Ceramics	5
Miscellaneous	5
Paper	4
Tannery	4
Soap	4
Railroad yards	4
Total	272

wastes, but by October 1, 1954, 193 companies had responded.

Review of the 879 questionnaires showed that 272 companies (Table II) were subject to the service surcharge. The remainder were placed in the open file for further study. Laundries are charged $0.251 per 1,000 lb., based on the weight of dry wash each month; linen suppliers are charged $0.218 per 1,000 lb., based on the dry weight of towels washed per month; dairy products companies are charged $0.395 per 1,000 lb. of skim milk processed.

The second step was gaging, sampling, and laboratory analysis. The several operations involved in the gaging, sampling, and analysis of the wastes from a particular industry may be classified under three headings: (a) preliminary investigation, (b) gaging and sampling, and (c) laboratory analysis.

Preliminary Investigations

After it has been decided by the industrial wastes unit that a particular industry is to be scheduled for gaging and sampling, a preliminary study is made to determine the types and sources of wastes being discharged, the sampling points to be used, the types of flow measuring devices to be employed, the hours of the day during which samples are to be taken, the over-all duration of the program, and a general idea of the specific analytical determinations which will be made.

This information is obtained from the questionnaires returned by the industries, by field investigations, from the sewer tap records, or by a combination of these expedients. Most of the information can be obtained from the completed questionnaires, which include a plant layout of building, sewers, and sampling point locations. In many cases, however, the questionnaires were returned incomplete, and the missing information must be obtained by field observation and study of sewer tap records.

An idea of the types and constituents of the wastes being produced at a plant can be formulated by knowing the kinds and quantity of raw materials used in both the manufactured products and the manufacturing processes. A field investigation by personnel of the industrial wastes unit will disclose such information as sources of wastes, the best sampling points, and flow measuring devices best suited to the sampling points.

Knowledge of the hours of operation of the plant, and the variations of plant processes during the day and the week, can be used to establish the times and duration of the sampling program, and the frequency of sampling.

Gaging and Sampling

After the gaging and sampling program has been set up through the preliminary investigations, a field crew is sent out to establish the sampling stations and to install the sampling and flow measuring devices. Weirs, including 90° V-notch, rectangular, and circular weirs, are most commonly used to measure flows, the 90° V-notch type being most preferred. However, in some installations, usually involving low or intermittent flows, the volumetric method, requiring the

use of a stop watch and a container of known volume, is used. In other instances, where weir installations are impractical, the depth-slope method of flow measurement is used. Generally, every sampling point presents different problems in selection and installation of flow measurement devices.

The Sewage Disposal Section has designed two steel weirs (Figure 6), of 48-in. and 30-in. basic size. Adjustable side pieces have been designed to be added to each basic weir, increasing its size so that each weir can be utilized for three sewer sizes; that is, the 48-in. weir can be expanded to 60 in. and 72 in., the 30-in. weir expands to 42 in. and 54 in. An adjustable steel arch band was designed to lock the various size weirs in place, eliminating the drilling of holes in the sewer. The life usage of the steel weirs is endless.

After the stations are set up, they are manned by gaging and sampling personnel, who work on 8-hr. shifts for as many shifts as determined by the duration of flow. For most of the larger industries, gaging and sampling is conducted around the clock for five to seven days, at intervals varying from 15 to 30 min. according to the type of flow.

It is the responsibility of gaging and sampling personnel to collect the samples at the required time intervals, and at the same time obtain the flow readings and determine the pH of the samples. These data are recorded on field sheets along with notes of any unusual occurrences, weather or otherwise. Individual grab samples are composited, in proportion to flow, into 24-hr. composite samples by field personnel. A 24-hr. composite from each station is taken daily to the laboratory for analysis. Samples are preserved

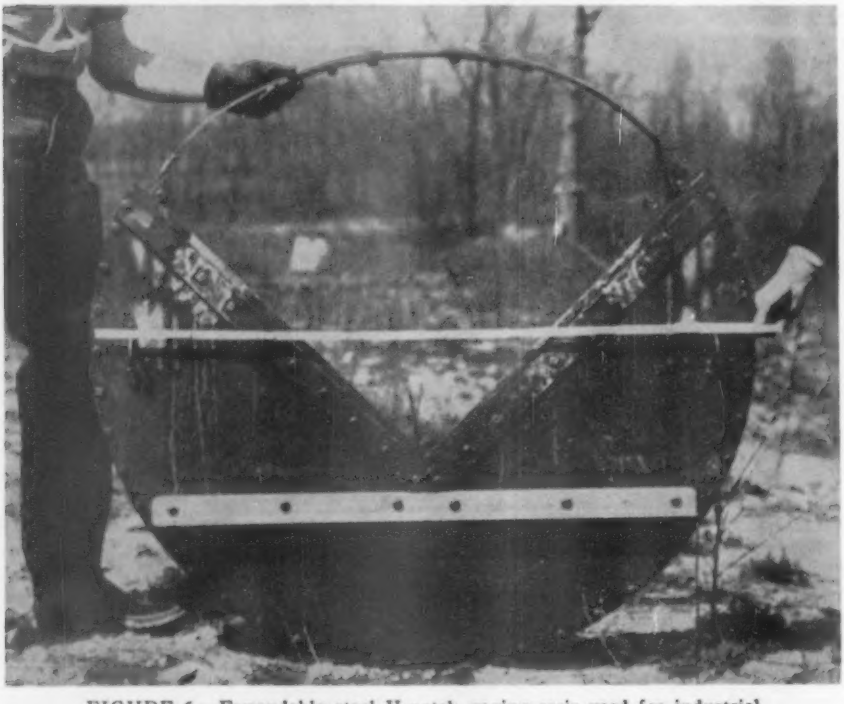

FIGURE 6.—Expandable steel V-notch gaging weir used for industrial discharge measurements.

by refrigeration in the field and every precaution is made to exclude dirt and other foreign matter which might affect the analysis.

Laboratory Analysis

It is the work of the Industrial Wastes Laboratory, at present located at the Little Miami sewage treatment works, to perform the necessary chemical analyses on the samples collected in the field. All samples, regardless of source, are analyzed for suspended solids, B.O.D., pH, and ether soluble matter. Other determinations are made, depending on the nature and sources of the wastes. Spot tests are used which indicate qualitatively the presence or absence of other constituents which are in violation of the rules and regulations. If a positive spot test on any constituent is obtained, a quantitative analysis is then carried out to determine the quantity of the substance indicated.

The laboratory recently purchased a spectrophotometer with ultraviolet attachments. This device is being used extensively for the colorimetric determination of metallic ions in sewage. The highly sensitive apparatus is of a type used by the U. S. Bureau of Standards, and results obtained with it are accepted as standard by analytical laboratories all over the country. Another use to which the spectrophotometer will be put is for the analysis of organic matter in the wastes by the ability of such material to absorb ultraviolet light. With the proper attachments, the apparatus can also be used for flame determinations.

All determinations are made according to the procedures set forth by the latest edition of "Standard Methods for the Examination of Water and Sewage."

Final analysis data are conveyed to the industrial wastes unit, where they are assimilated into over-all final results, which are then used to compute the sewerage surcharge and form the basis for proper action against prohibited constituents.

Of interest is a monthly report of the work load of the laboratories. During June 1954, 383 determinations were made on 46 composite samples, which in turn were composed of 3,838 field grab samples from eight companies.

Problems encountered in the application of the surcharge on industrial wastes stemmed mainly from the differences in the methods in gaging and sampling of wastes, and subsequent chemical determination of the strength of constituents.

Many of the analyses from industry differed greatly with the results obtained in the industrial wastes laboratory and the difference in the analyses can be attributed to the departure, by industry, from the "Standard Methods," and lack of proper sampling and gaging methods.

Of a total of 41 companies gaged and sampled by city forces, and having previously submitted analyses of their own, 24 showed higher waste strengths by city analysis than by company analysis and 17 showed higher waste strengths by company analysis than by city analysis. In no instance were the city analyses equal to the company analyses. Five companies originally not subject to the sewerage surcharge because their own analyses indicated less than "normal" strengths, have been charged the surcharge because the city's analyses indicated greater than "normal" strengths. Conversely, the sewerage surcharge was dropped from two companies as a result of the city's analyses showing lower strengths than the companies' analyses. For 17 companies the surcharge was increased as a result of city gaging and sampling, and for 13 companies the surcharge was decreased as a result of city gaging and sampling (Table III).

To explain the differences between the city's analyses and the companies'

TABLE III.—Comparison of City *vs.* Industry Analyses of Industrial Wastes

Industry Classification	Number of Companies Compared	Companies' Analyses Greater than City's	Companies' Analyses Less than City's
Creamery, milk industry	1	1	—
Slaughter and meat packing	10	5	5
Food products	12	5	7
Leather and tannery	1	1	—
Textiles and cloth manufacturing	2	2	—
Metal processing and plating	5	4	1
Chemical	7	3	4
Ceramics, asphalt, masonry	1	1	—
Dry cleaning, laundry	1	1	—
Railroad yard	1	—	1

analyses is difficult, since in most cases the companies failed to submit an account of their sampling procedures along with their analyses. In many instances, however, company gaging and sampling techniques were faulty, resulting in failure to obtain representative samples of wastes for final analysis. The most frequently encountered errors in sampling and gaging techniques are listed as follows, along with a typical example for each type:

1. Analysis of one grab sample not representative of the total flow. *Example:*—A small meat packing company submitted to the city the analysis of one grab sample taken from a dirty sump. Analysis of this sample showed 2,165 p.p.m. B.O.D. and 3,643 p.p.m. suspended solids. A city sampling and gaging program which included sampling of all flows at 15-min. intervals and compositing proportional to flow showed 633 p.p.m. B.O.D. and 473 p.p.m. suspended solids. As a result of correct sampling and gaging procedures by the city, the surcharge for this company was reduced by nearly 90 per cent.

2. Failure to composite individual grab samples proportional to the flow rate. *Example:*—A large poultry killing and dressing plant sampled their wastes at regular time intervals and composited their samples by equal portions without taking flow rate into consideration. Analysis of the resulting composited samples showed 2,400 p.p.m. B.O.D. and 2,884 p.p.m. suspended solids. City forces gaged and sampled the wastes at the same sampling points, but the composite was made proportional to flow rate, which produced an analysis of 488 p.p.m. B.O.D. and 265 p.p.m. suspended solids. In this case the surcharge was reduced by 94 per cent.

3. Failure to include all points of discharge into city sewers in the gaging and sampling program. *Example:*—A large baking company gaged and sampled their process wastes, but did not include their cooling water in the program. Their analysis showed 14,100 p.p.m. B.O.D. and 4,767 p.p.m. suspended solids. The city analysis of samples which included the cooling water showed 5,920 p.p.m. B.O.D. and 3,482 p.p.m. suspended solids. The surcharge was reduced approximately 50 per cent by using correct procedures.

4. Failure to sample and gage at sufficient time intervals and over a sufficient time period to obtain representative samples of flow from all processes during total operation periods. *Example:*—A tannery whose processes vary considerably from hour to hour and day to day engaged an outside firm to gage and sample their wastes. All waste discharges were included in the program and samples were composited correctly, but samples were taken only every hour over a

single 24-hr. period. The resulting final analysis showed 190 p.p.m. B.O.D. and 525 p.p.m. suspended solids. City forces gaged and sampled these wastes at 15-min. intervals over a period of five consecutive days. Weighted averages of the strengths produced final results of 372 p.p.m. B.O.D. and 1,424 p.p.m. suspended solids. This company's surcharge was increased about 570 per cent by the use of correct procedures.

5. Improper selection of sampling points and improper sampling techniques. *Example:*—A plant producing commercial inorganic chemicals was gaged and sampled by city forces. Because of a lack of sampling points at which all wastes could be properly sampled and gaged, and due to blind connections into the street sewer, wastes were sampled from the street sewer above and below the plant and final strengths determined by differentiation. However, the wastes of this industry were such that chemical changes were produced in the total flow between the sampling points and negative results were obtained. This analysis could therefore not be used to apply the surcharge and another method of sampling had to be devised.

6. Improper selection, installation, functioning, and reading of flow measurement devices. *Example:*—A large meat packing company spent a considerable sum for installation of pretreatment equipment for their wastes. Included in the design was a manhole to be used for gaging and sampling. When city forces tried to install a weir in the gaging manhole it was found that the channel through the manhole was too small for the volume of flow and that the elevation of the manhole was such that any obstruction would back the flow up into the treatment device. The gaging manhole was thus totally useless for gaging purposes and flow measurement had to be accomplished in another manhole.

Comments on Gaging and Sampling Program

It is necessary that every phase of the industrial wastes gaging and sampling program be carried out to the highest practical degree of care and precision, since the results are the basis of charge to the industries. Installation men must use every precaution to install flow measurement devices correctly and permanently. Gagers and samplers must be able to read flow measurement devices correctly and accurately and to perform the necessary field calculations pertaining to compositing the samples. They must use all precautions to collect samples properly and to keep all dirt and foreign material out of the samples. Laboratory personnel must be capable of performing the necessary analyses with the degree of precision and accuracy required in any analytic laboratory.

The difficulties encountered in this program are frequent and numerous. Nearly every industry to be gaged and sampled presents its own unique problems in the form of location of sampling points, and difficulties in installation of gaging apparatus. To meet these problems, field supervisors and installation men are called upon to use both imagination and ingenuity.

The city is constantly searching for new methods and techniques of gaging, and sampling, and analysis of industrial waste. The laboratory is equipped with the latest instruments and apparatus to insure accurate and quick determinations. Field equipment has been purchased and used to greatly decrease the human error element in sampling and gaging. Up-to-date techniques are constantly being studied and used. A field trailer (Figure 7) has been built with a recording pH meter, a recording flow meter and a self-contained power plant for use where power from industry is not available. The trailer is pulled

FIGURE 7.—Field trailer for gaging and sampling of industrial wastes includes self-contained power plant.

up to a manhole or observation point and gives a positive printed record of the conditions found at the industry being gaged and sampled. Where an industry disagrees with the city's analyses, a rerun may be made, with the industry paying either one-half the cost or the total cost of the rerun, depending on the circumstances. The city has experienced four such situations since the surcharge was placed into effect. The results are given in Table IV, which shows that three out of the four reruns resulted in higher strengths, with resultant increases in the sewerage surcharge. (In Table IV, K is the rate of sewerage surcharge per unit volume of water used. It is determined by applying the determined B.O.D. and suspended solids concentrations to the surcharge formula.)

Surcharge Set-Up Practice

To set up sewerage surcharges without the advantage of specific analytical data was not easy. In the event that a plant or premise failed to send the city an analysis of the waste discharged to the sewer system, such charges were based on comparable figured charges, based on city analysis of companies having similar processes, or on figures of that type of industry available from statistics of the U. S. Public Health Service or other available national figures.

Conversely, after a gaging and sampling operation and subsequent chemical analysis made by city forces, this office has found, in some instances, that applied figures used from other sources did not apply to some types of manufacturing processes. The results found are applied to the local situation only, and are believed to be true results developed from careful observations, sampling and measurements of flow wastes, and laboratory procedure as directed by "Standard Methods."

The development and application of the sewerage service charge and the sewerage surcharge has made industry water conscious. In fact, many companies have re-evaluated their water supply facilities and have subsequently introduced conservation programs. Table V shows that in three local breweries as water usage increases, the strength of the wastes de-

TABLE IV.—Comparison of Results Between Initial City Analyses and Company Requested Reruns

Co.	Type	1st Analysis				2nd Analysis			
		B.O.D. (p.p.m.)	Susp. Sol. (p.p.m.)	Ether-Sol. (p.p.m.)	K[1] ($/100 cu. ft.)	B.O.D. (p.p.m.)	Susp. Sol. (p.p.m.)	Ether-Sol. (p.p.m.)	K[1] ($/100 cu. ft.)
A	Industrial laundry	770	1,407	1,182	0.115365	1,195	2,265	1,479	0.202729
B	Industrial laundry	657	355	500	0.037219	529	309	386	0.023884
C	Domestic laundry	420	170	603	0.014508	539	176	322	0.024099
D	Industrial laundry	2,300	1,628	1,837	0.272874	1,199	3,040	2,064	0.298139

[1] Rate of sewerage surcharge per unit volume of water used; calculated by applying the determined B.O.D. and suspended solids concentrations to the surcharge formula.

TABLE V.—Water Use, Waste Concentrations, and Sewer Service Charges for Three Cincinnati Breweries

Company	Water Use (gal./bbl.)	B.O.D. (lb./bbl.)	Susp. Sol. (lb./bbl.)	Sewer Charge ($/bbl.)		
				Service Charge	Surcharge	Total
1	245	2.03	0.48	0.028	0.020	0.048
2	346	1.90	0.92	0.039	0.016	0.055
3	395	1.50	0.83	0.045	0.007	0.052

creases. The table also shows the sewer service charge and the sewerage surcharge for the same three breweries, all of which sell their spent grains and yeast to a processing company.

As a result of the ordinance and the industries' interest in reducing their surcharge, and because of agreements wherein they could recapture money paid on the surcharge, 24 have built pre-treatment works for removal of solids, paunch manure and greases (meat industries); for the removal of solids, correction of acids and caustic materials and color (chemical industries); for the removal of grease (rendering plants); for the correction of acid conditions and the recapture of metals (metal-plating industries); for the removal of solids caused by treatment of water (railroads); and other miscellaneous treatment works.

It is estimated that industry has spent $2,000,000 on internal plant changes, either housekeeping methods or process changes; and about $2,500,000 on pre-treatment facilities. Industry has cooperated practically 100 per cent to make the ordinance workable.

A word of caution must be given concerning the ordinance, as follows: The Industrial Waste Ordinance was designed, formulated, and placed in operation based on the experience of the Cincinnati industrial surveys and consultation with industry for three years. It is applicable only to the Cincinnati metropolitan sewage disposal program and should not be taken in whole for other cities. Instead, other cities should study their needs and use their own good judgment in passing local ordinances. Moreover, when an industrial waste ordinance is passed, two important items are extremely necessary to its enforcement. The first is the provision of sufficient Man-Power to carry out the edicts of the ordinance; the second, infinite patience.

Acknowledgments

Grateful acknowledgment is made to the following Sewage Disposal Program personnel who furnished data and guidance in the preparation of this paper: Fenton H. Dobb, Senior Engineer; Dean Taylor, Senior Sanitary Engineer; Carl Vollmer, Edward Fisher and John Stanton, Assistant Engineers; John Sigler, Industrial Waste Chemist; and Samuel Shafer, Assistant Superintendent (Treatment).

MECHANICS OF OXYGEN ABSORPTION IN SPIRAL FLOW AERATION TANKS

I. Derivation of Formulas

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A tremendous amount of energy is expended daily in compressing the air that must be supplied to the many aeration tanks now in use in sewage treatment plants. Air is the source from which oxygen enters solution to sustain the life of organisms functioning in the activated sludge process of sewage treatment. If power costs are to be reduced and kept at a minimum, a thorough understanding must be acquired of the factors involved in dissolving oxygen from air under conditions such as normally occur in sewage treatment.

The theory of the mechanism of oxygen absorption is already well known (1). However, despite this fact, very little has been done toward converting such knowledge to a practical form. Certainly a better general knowledge of the factors affecting oxygen absorption properly related in useable form must be acquired if the efficiency of the activated sludge process is to be developed to the fullest extent possible.

Experimental data (2)(3) have been published on the absorption of oxygen from air bubbles rising through water partially saturated with dissolved oxygen. Also, data are available (4) on experiments on atmospheric reaeration of water under stream flow conditions. But, to the author's knowledge, there is nothing in published form in which these data have been combined in the derivation of formulas for computing the rates of absorption of oxygen by water in aeration tanks such as are now in general use in the activated sludge process of sewage treatment.

The circulating velocities have been measured in spiral flow aeration tanks. At Indianapolis (5), in 1922, the bottom velocities were gauged. In the Sanitary District of Chicago, velocities at top and bottom were measured as a guide in tank design in 1924 and 1925, subsequently in 1930, and again in 1945. The latest tests included, in addition to surface and bottom velocities, measurements of the rising currents above the air diffusers, thus providing a basis for estimating bubble detention.

About 1945 the author, in working out a method for determining the economical depth of aeration tanks, used the foregoing velocity measurements and data on oxygen absorption from air bubbles and from atmospheric reaeration to compute the rates of absorption of oxygen by water in spiral flow aeration channels 15 ft. 6 in. in depth (15 ft. on porous plate diffusers) by 34 ft. 9 in. center to center of walls. By means of the hydraulic model theory, it was possible to apply the data to various depths of channels and derive formulas for general application.

Considerable uncer inty existed at that time as to how dependable the formulas were and as to the effects on the rate of oxygen absorption by water of such factors as temperature and substances normally present in sewage and activated sludge. Also, there were no means available for an experimental check on the computations. However, between 1951 and 1954 tests in the Sanitary District of Chicago with model tanks and on large aeration tanks have provided

data on the formulas and the factors to be considered in their application.

The derivation of the formulas from available data is described herein. In their final form they show the relation of the various factors influencing the rate of oxygen absorption in spiral flow aeration tanks. With such knowledge the engineer is much better equipped to analyze and solve the problems involved in the design and operation of the activated sludge process.

Oxygen Absorption from Air Bubbles

Measurements of the oxygen dissolved from air bubbles have been made by several investigators. It has been established (6) that when partially saturated water and small air bubbles are allowed to come in contact and the water is kept thoroughly mixed so that it may be regarded as of uniform composition at all points, the rate at which oxygen enters solution at any particular temperature is directly proportional (a) to the area of bubble surface and (b) to the difference between the dissolved oxygen concentration in the saturated water in the interface or bubble film and that in the main body of the water. The bubble surface per unit of air volume varies inversely as the diameter. The concentration of oxygen in the saturated water film coating the bubbles varies directly as the partial pressure exerted by the oxygen in the air bubble.

Scouller and Watson (2) measured the oxygen dissolved from air bubbles of 0.0945-in. diameter rising 1.25 ft. through a tube of water partially saturated with dissolved oxygen. The temperature was held constant at 15° C. Tests were run with both an open and an oil-covered surface. There was, however, no substantial difference in results. Under the latter condition, which prevented atmospheric reaeration, the test data indicated that the oxygen absorption per p.p.m. under saturation averaged about 0.0076 lb. per day per sq. ft. of bubble surface. It was noted, however, by Scouller and Watson that a higher absorption rate took place in the upper portion of the tube and this was attributed to the bursting of the bubbles at the surface. By measuring absorption in the upper and lower portions of the tube it was possible to compute the effect of the bursting of the bubbles. The absorption from this source accounted for about 22 per cent of the total or about 34 per cent of the absorption per foot of bubble rise. Correcting for this, the oxygen absorption per p.p.m. under-saturation must have averaged about 0.0059 lb. per day per sq. ft. of bubble surface while rising through the water.

Tests made later by Scouller and Nixon (3) closely checked the foregoing results. Measurements were made of the rates of absorption of oxygen from air bubbles rising through a 9-ft. column of partially saturated water. The bubbles were of four different diameters; 0.043, 0.063, 0.143, and 0.178 in. The sizes were those as they entered at the bottom of the water column. Under the same conditions of temperatures and dissolved oxygen content in the water column the rate at which oxygen dissolved varied inversely as the diameter of the bubbles. The results of 3 out of about 40 are reported in Table I. These 3 tests were purposely selected in which the changes in the dissolved oxygen of the water were relatively small and in which the percentage of oxygen absorbed was low in order to avoid errors in computations.

The absorption rates in Table I were computed by the author from the data reported. The tests were run at about sea level. A sample computation is given below for bubbles of 0.178-in. diameter. The weight of a cubic foot of free air at 16.5° C. is 0.076 lb., of which 23.1 per cent by weight is oxygen occupying 20.9 per cent by volume.

D.O. in water: Beginning = 0.46 p.p.m.; end = 1.09 p.p.m.; average = 0.8 p.p.m.

Oxygen absorbed:

Total = 16.45%

Bubble bursting $\frac{0.34}{9.34} \times 16.5 = 0.60\%$

Bubble surface only = 15.85%

Original air remaining at top of rise through water = $100 - 15.85 \times 0.209 = 96.7\%$

Bubble film D.O. sat. at bottom = $\frac{18.6}{14.7} \times 9.8 = 12.4$ p.p.m.

Bubble film D.O. sat. at top of rise = $\frac{1.00 - 0.1585}{0.967} \times 9.8 = 8.5$ p.p.m.

Consider 1.0 cu. ft. of air entering at bottom. Then:

Bubble volume at bottom = 1.0 cu. ft.
Bubble (0.178 in. dia.) surface at bottom = 402 sq. ft.

Bubble volume at top = $0.967 \times \frac{18.6}{14.7} = 1.215$ cu. ft.

Bubble dia. at top = $(1.215)^{\frac{1}{3}} \times 0.178 = 0.203$ in.
Bubble surface at top = $1.215 \times 355 = 430$ sq. ft.

Try 0.0063 lb. per sq. ft. per day oxygen absorption per p.p.m. of D.O. differential.

Absorption rate from bubbles at top of rise = 430 (8.5–0.8) × 0.0063 = 20.8 lb. per day

Absorption rate from bubbles at bottom of rise = 402 (12.4–0.8) × 0.0063 = 29.4 lb. per day

Average = 25.1 lb. per day

Total absorption in 12-sec. rise = $25.1 \times \frac{12}{86{,}400} = 0.0035$ lb.

Total absorption of oxygen in air = $\frac{0.0035 \times 14.7}{0.076 \times 0.231 \times 18.6} = 15.8\%$ (Check)

TABLE I.—Oxygen Absorption Rates from Air Bubbles Rising in 9 Ft. of Water [1]

Jet Diam. (in.)	Bubbles			Temp. (°C.)	D.O. in Water (p.p.m.)			Oxygen Absorption		
	Diam. (in.)	Rising Time (sec.)	Rising Velocity (ft./sec.)		Before Aeration	After Aeration	Sat.	Per Cent	Computed[2] Absorption[3]	
									No N_2 Absorp.	$N_2 = O_2$ Absorp.
0.0039	0.063	10	0.9	20.0	0.35	2.64	9.2	31.54	0.0065	0.0064
0.0119	0.143	12	0.75	22.0	0.46	1.84	8.8	18.93	0.0068	0.0067
0.0330	0.178	12	0.75	16.5	0.46	1.09	9.8	16.45	0.0063	0.0062

[1] Data from Reference (3).
[2] Computed by current author.
[3] In pounds per square foot per day per p.p.m. D.O. differential.

It is to be noted that the effect of the bursting of the bubbles is taken into consideration in the foregoing computation. If the oxygen entering solution from this source is equivalent to 34 per cent of that from the bubble surface while rising 1 ft., then it amounts to only 0.34/9.34 or 3.6 per cent of the total for a bubble rise of 9 ft. in stationary water.

However, the absorption from the bursting of the bubble may have a greater relative importance in the case of an aeration tank where, due to rising currents, the air bubbles might, for example, move upward 15 ft. in 6 sec., the water moving at 1.75 ft. per sec. as the bubble slips upward at an additional velocity of 0.75 ft. per sec. In the 6 sec., the bubble would move upwards in relation to the water only 4.5 ft. In this case the oxygen absorption on bursting would be 0.34/(4.5 +0.34) or 7.0 per cent of the total.

In the foregoing computation on oxygen absorption from 0.178-in. air bubbles the effect of nitrogen absorption on the reduction of bubble size is not included. There is no doubt that some absorption of nitrogen from the air in the bubbles took place, since the bubbles were allowed to rise through water that had been previously boiled to remove the dissolved oxygen. This, of course, also removed the dissolved nitrogen, making the reentrance of nitrogen into solution from the air bubbles a certainty. Scouller and Nixon concluded that the nitrogen was absorbed at a lesser rate than oxygen.

Other investigators (7) have found that the rates of solution of gases in water vary as the difference in concentration of the solute on the two sides of the interface. If this is true, the rate at which nitrogen was dissolved must have exceeded that for oxygen, since saturation for dissolved nitrogen in water at sea level at 16.5° C. is 16.5 p.p.m., and for oxygen only 10.5 p.p.m. Since the dissolved gases in the water used in the tests were quite low, the relative rates of solution must have been approximately at the saturation values. Thus the rate of absorption of nitrogen must have exceeded that of oxygen by about 60 per cent. In order to get an idea of the effect of the absorption of nitrogen on the computed rates of oxygen absorption, they were figured assuming both of these gases were absorbed in equal amounts. The results are given in the last column of Table I. Only a small difference in the computed oxygen absorption rate is indicated.

In computing the oxygen absorption from air bubble surfaces, an average of the rates at the bottom and top of the water column was used. This method might be questioned, but additional study showed it to be reasonably correct. If the computed average rates for the two halves or the four quarters of the bubble rise are used, the final results remain practically unchanged. This indicates that the rate of absorption from a single bubble changes at a uniform rate as the bubble rises through water.

As a result of a study of the tests made by Scouller, Watson and Nixon, it was concluded that the oxygen absorption rate from air bubbles while rising in water at 20° C. is about 0.0065 lb. per sq. ft. of bubble surface per day per p.p.m. of dissolved oxygen differential across the interface.

It is to be noted that the oxygen absorption from air bubbles is based on an absorption rate per unit of time during the upward rise of the bubbles plus an additional amount occurring just as the bubbles break the surface, equivalent to a 0.34-ft. rise through water. This additional absorption at the water surface Scouller and Watson (2) attributed to the bursting of the bubbles.

It might also be attributed to the shedding of the oxygen-saturated films by the bubbles. If it is assumed that

oxygen molecules from the air striking a water surface penetrate it, causing dissolved oxygen saturation for a slight distance, it can be shown that this distance needs to be only very minute to account for the added absorption of oxygen from the bubbles right at the water surface. Bubbles slip upward in water at about 0.75 ft. per sec. To slip up 0.34 ft. would require only 0.45 sec. At 20° C. and a rate of absorption of 0.0065 lb. per day per sq. ft. of bubble film per p.p.m. D.O. differential, would mean the shedding of an oxygen-saturated bubble film of only 0.0065-in. thickness to equal the absorption occurring in a rise of 0.34 ft. It does seem probable that this is a reasonable explanation of the oxygen absorption occurring just as the bubble breaks the surface.

Using the foregoing oxygen absorption rate for the rising air bubbles and the bubble bursting effect at the surface, it is possible to compute the percentage of oxygen absorbed from a bubble rising at a uniform rate in a given time through a certain vertical distance by slipping upward in a uniformly rising current of water. This can be done by the same type of computation as illustrated previously, except that the rate of absorption per unit area of bubble is known and the percentage of oxygen absorption is determined by trial and check. By setting up a number of conditions for bubble diameter, water depth, and bubble detention, and by logarithmic plotting of the results, the formula for oxygen absorption from air bubbles in water at 20° C. was derived as follows:

$$P = \frac{0.049\ H^{0.18}\ U^{Z}\ S^{0.86}}{d^{0.94}} \quad \ldots\ldots (1)$$

in which

P = percentage of oxygen absorbed from bubble;

U = oxygen deficiency of the water, in p.p.m., at atmospheric pressure;

S = bubble detention or rising time in the water, in seconds;

H = water depth to point where bubble enters;

d = bubble diameter, in inches; and

$Z = 1/H^{0.12}$

Eq. 1 applies to the oxygen absorption under conditions similar to those in spiral flow aeration channnels where the bubbles are slipping upward in rising currents of water. Subsequent tests to be described later indicated the oxygen absorption to vary about as $(1.024)^T$, in which 1.024 is the temperature coefficient and T is the water temperature in degrees Centigrade. Introducing this factor for temperature variation, Eq. 1 becomes:

$$P = \frac{0.031\ H^{0.18}\ U^{Z}\ S^{0.86}(1.024)^{T}}{d^{0.94}} \quad \ldots (2)$$

The formula was derived from computations on bubble diameters of 0.1 to 0.2 in., bubble detentions up to 10 sec., water depths from 1 to 30 ft., a water temperature range of 8° to 25° C., and oxygen deficiencies (at atmospheric pressure) of more than 50 per cent.

It should be pointed out that the pressure of the air in a rising bubble exceeds atmospheric pressure and therefore the dissolved oxygen in the water can be increased to more than 100 per cent saturation, referred to atmospheric pressure. In Eq. 2, the oxygen deficiency is that for water at atmospheric pressure. Therefore, Eq. 2 has its limitations and should be restricted in application to conditions where the dissolved oxygen of the water in reference to atmospheric pressure is less than 50 per cent of saturation.

Since, as previously pointed out, the oxygen absorption from a rising air bubble in water decreases at an approximately uniform rate, the rate at half depth is an approximate average

for the entire rise. Hence, the absorption rate must vary about as the dissolved oxygen differential between the bubble film and the water at this particular depth. If the oxygen deficiency is expressed as the deficiency for the pressure of half depth, Eq. 2 may be converted to include this deficiency and used for any particular condition. For example, if bubbles are rising through 10 ft. of 20° C. temperature water with an atmospheric pressure of 760 mm. (14.7 lb. per sq. in.), the oxygen saturation for atmospheric pressure would be 9.17 p.p.m. and for the additional half-depth pressure of 5 ft. of water, 10.6 p.p.m. Eq. 2 can then be converted, using the condition zero dissolved oxygen in the water for making the transition. The constant should be multiplied by $[(9.17)^1/_{10}^{0.13} \div 10.6]$ and the formula becomes, for a 10-ft. water depth:

$$P = \frac{0.0227\ U_h\ S^{0.86}(1.024)^T}{d^{0.94}} \quad \ldots\ldots (3)$$

in which U_h is the oxygen deficiency for the pressure at the half depth of 5 ft. In this form, the formula applies over the range of values of U_h from zero to saturation.

Eq. 2, as derived in terms of oxygen deficiency at atmospheric pressure, has sufficient range for the conditions normally encountered in the activated sludge process. Conversion to the form of Eq. 3 may be desirable under special circumstances.

Oxygen Absorption from Atmosphere

The results of several tests are available on oxygen absorption from the atmosphere by partially saturated water. It is generally known that the absorption rate at the water surface varies directly as the oxygen undersaturation and as some function of the surface velocity, increasing with velocity. Streeter, Wright and Kehr (4) conducted tests on the relation of surface velocity in streams to atmospheric reaeration. The results of their tests are, therefore, of considerable value in determining the oxygen absorption rates at the surfaces of aeration tanks.

The tests were made in several different channels and were run on water deaerated by iron filings or by means of sodium sulfite and also on sodium sulfite solution. The channel for which the velocity influence was reported was 3 in. wide by about 4 in. water depth. For velocities of 0.15 ft. per sec. and less, the oxygen absorption varied about as $V^{0.81}$. For higher velocities, at which the flow was definitely turbulent, the rate of absorption varied about as $V^{1.78}$. The results at the higher velocities with deaerated water and sulfite solution agreed closely. An analysis of the test data by the author indicated the oxygen absorption at the higher velocities to be about $0.0395V^{1.78}$ lb. per sq. ft. of surface per day (at sea level and zero dissolved oxygen), in which V is the surface velocity in feet per second.

Streeter *et al.* analyzed the results of their experiments to determine the effect of the temperature of water on the rate of oxygen absorption. The data used were from a channel of 3-in. flow depth with velocities of 4.6 ft. per min. and less, and also from a channel of 9-, 12-, and 15-in. flow depth with velocities of 25 ft. per min. and less. The conclusion was that for zero dissolved oxygen and barometric pressure of 760 mm. mercury, the rate of absorption increased about 1.6 per cent for each degree Centigrade increase in the temperature of the water.

The foregoing conclusion probably holds true for very low velocities in shallow channels, and possibly for quiescent deep streams in which the dispersion of the dissolved oxygen is not too rapid. On the other hand, where the mixing of the dissolved oxygen is rapid and complete there is

much evidence to indicate that the rate at which oxygen enters solution at 100 per cent undersaturation increases at a lower rate than indicated by Streeter's tests.

Adeney (8) measured the rate of atmospheric reaeration for zero dissolved oxygen in water at various temperatures. The results, as pointed out by Edmonson and Goodrich (9), indicated the rates at which oxygen goes into solution at 100 per cent undersaturation to be equal for all temperatures. In the author's tests on diffused-air aeration, to be described later, the rate of absorption at zero D.O. was found, however, to increase slightly with a rise in water temperature varying from zero at 5° to 0.4 per cent per degree rise at 25° C.

The rate of 0.0395 $V^{1.75}$ lb. per sq. ft. per day oxygen absorption by atmospheric reaeration, at 100 per cent undersaturation, is an average of the results reported by Streeter *et al.*, on tests on water varying from 17° to 23° C. in temperature. However, the effect of temperature on the absorption rate at 100 per cent oxygen deficiency was very slight for a 6° temperature range and for that reason it may be assumed that this average rate occurred at 20° C., at which the oxygen deficiency was 9.17 p.p.m.

Therefore, the rate of oxygen absorption from atmospheric reaeration per p.p.m. deficiency at 20° C. water temperature must be about 0.0395/9.17 or 0.0043 $V^{1.75}$ lb. per day per sq. ft. of water surface. This is the rate used as a basis for this study. It is quite probable that it holds true only when the turbulence is sufficient to insure a rapid and uniform dispersion of the dissolved oxygen in the water, a condition which must certainly obtain in aerated channels.

Oxygen Absorption Rates from Bubbles and Atmosphere Related

It is necessary to know the velocities at which air bubbles slip up through water in order to show how the rate of oxygen absorption from rising bubbles is related to atmospheric reaeration. The effect of bubble diameter

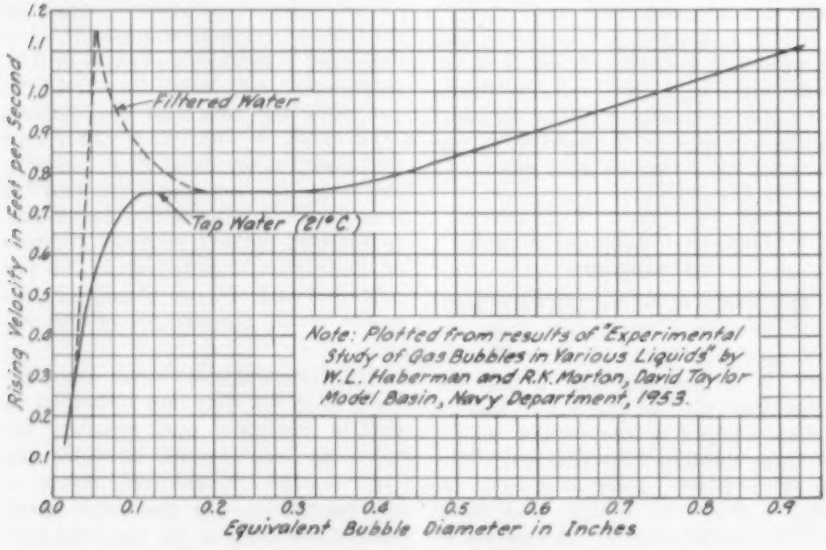

FIGURE 1.—Rising velocity of air bubbles in tap water.

on its rising velocity in quiescent water is shown in Figure 1. The curves were plotted from data obtained in tests by Haberman and Morton (10). Small bubbles rise faster in filtered than in tap water. It is believed that filtering removes small particles that tend to collect at the bubble surfaces, increasing their resistance to movement. This effect, however, diminishes and finally disappears as the bubble diameter increases. Fine bubbles are spherical. Larger bubbles, such as occur in the diffused air of the activated sludge process (0.10- to 0.20-in. diameter), are flattened (that is, ellipsoidal) in shape, whereas very large bubbles assume a spherical cap shape.

Of particular interest from the standpoint of this study is the fact that air bubbles slip up through tap water at about 0.75 ft. per sec. for the range of weighted average diameter (0.1 to 0.2 in.) normally present in diffused air in the aerated sludge process. Prior to the publication of the results of the tests by Haberman and Morton, the author had reached the same conclusion from the results of tests by Miyagi (11) and Scouller and Nixon (3).

If the rate of atmospheric reaeration for water at 20° C. (0.0043 $V^{1.75}$ lb. per day per sq. ft. of surface per p.p.m. oxygen deficiency) were applied to air bubbles, the movement of the bubble surface relative to the contiguous water would have to be about 1.26 ft. per sec. to give the rate of 0.0065 lb. per day per sq. ft. per p.p.m. oxygen differential, which tests previously described have indicated. When a bubble moves upward, the water from just above it must be continually flowing down around the bubble to fill the space being vacated below. This means that the water adjacent to the bubble film is moving faster relative to the bubble surface than the velocity of upward slip of the bubble.

Also, bubbles do not rise vertically. Instead, they slip up spirally, thus moving faster through the water than the average upward velocity relative to the water. The difference between an upward bubble velocity of 0.75 ft. per sec. and 1.26 ft. per sec. can reasonably be attributed to the downward movement of the water immediately adjacent to the bubble plus the additional velocity due to the sideward slip of the bubble. Therefore, it seems probable that the rate of oxygen absorption through bubble films is about the same function of the velocity of the water, relative to the air-water interface, as obtains for stream surfaces.

Velocities in Aeration Tanks

The Sanitary District of Chicago measured the horizontal velocities in a 15 ft. 6 in. depth (15-ft. depth to plate diffusers) spiral flow aeration tank in 1930. The results are of particular value as a basis for computing oxygen absorption. A section of the channel is shown in Figure 2 with the points indicated at which the velocities were measured. The results (Table II) are the averages of velocities for three different sections along the channel. The tank had four rows of porous plates and was tested with two and also four rows (adjacent to wall) operating, corresponding to a diffuser plate area in relation to tank area of 5 and 10 per cent, respectively.

To compute the atmospheric reaeration it was necessary to know the surface velocities. These were obtained at any particular point in the cross-section of the tank by plotting the measured horizontal velocities against depth and extending the curve of velocity trend to the surface. From surface velocities thus obtained for three points in the tank width a curve was plotted (Figure 3) to show the velocity variation across the surface of the tank for any particular rate of air application. It is to be noted that higher velocities obtained in a

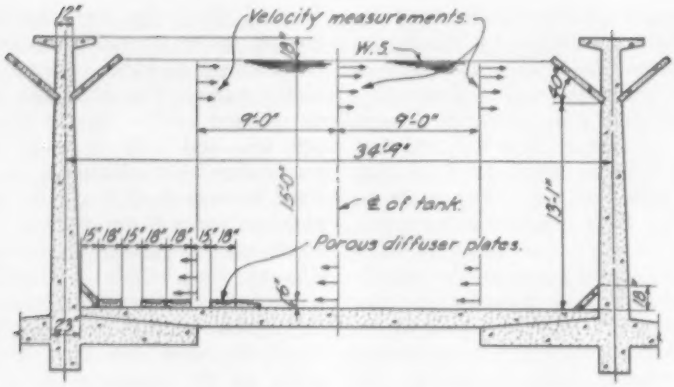

FIGURE 2.—Velocity measurements in aeration tank.

tank on the side of air application when two instead of four rows of diffusers were operating.

To use the velocity measurements for computing the oxygen absorption from air bubbles it was necessary to know the rising velocities in the bubble zone. It was possible to estimate these from measurements of rising velocities made in the Sanitary District in 1945 and, also, by averaging top and bottom velocities of the 1930 tests on the rising current side of the tank. Such estimates, however, were approximate, but due to the upward slip of the air bubbles any error in the estimated rising water velocity was reduced when used to compute the bub-

TABLE II.—Velocities in Spiral Flow Aeration Tank (34 Ft. to 9 In. Center to Center of Walls; 15-Ft. Depth to Diffusers)

Air (c.f.m./ 1,000 cu. ft.)	Depth Below Surface (ft.)	Horizontal Velocities (ft. per sec.)					
		Four Rows Diffusers Operating			Two Rows Diffusers Operating		
		Left 9 Ft.	Center Line	Right 9 Ft.	Left 9 Ft.	Center Line	Right 9 Ft.
6.0	0.5	1.66	1.76	1.43	2.35	1.83	1.57
	1.0	—	1.45	1.28	—	1.36	1.18
	1.5	1.26	—	—	1.30	—	—
	2.0	—	1.25	1.09	—	1.17	1.05
	2.5	1.06	—	—	0.83	—	—
	3.0	—	1.00	0.76	—	1.02	0.87
12.0	0.5	2.35	2.33	2.08	2.92	2.54	2.10
	1.0	—	2.09	1.71	—	1.95	1.82
	1.5	1.63	—	—	1.83	—	—
	2.0	—	1.60	1.22	—	1.55	1.39
	2.5	1.22	—	—	1.10	—	—
	3.0	—	1.39	1.07	—	1.05	1.16
18.0	0.5	2.91	2.96	2.39	3.34	2.77	2.23
	1.0	—	2.38	1.95	—	2.14	1.75
	1.5	2.18	—	—	1.98	—	—
	2.0	—	1.97	1.61	—	1.51	1.33
	2.5	1.65	—	—	1.48	—	—
	3.0	—	1.68	1.49	—	1.21	1.13

ble detention. From the test data the vertical velocities at half depth in the bubble zone, for two and four rows of diffusers operating, were estimated as 75 and 63 per cent, respectively, of the center horizontal velocities at half depth.

Oxygen Absorption Formulas

The oxygen absorption formulas are based on the test data previously discussed. In analyzing and converting the data to the form desired, a number of approximations were involved. Nevertheless, it was felt that the data in the converted forms were basically sound and sufficiently accurate to be used to set up formulas which would properly relate the factors involved in oxygen absorption in spiral flow aeration tanks. Tests made later could be used to make such modifications as were thought necessary.

The derivitations of the formulas are based entirely on oxygen absorption rates computed for the 15.5-ft. depth tank (15 ft. on the diffusers) shown in Figure 2. A 2-ft. length of channel was used as a basis in which the net liquid volume was 1,000 cu. ft. The total oxygen absorption is the sum of that from atmospheric reaeration and that from air bubbles. The absorption rate was computed for a water temperature of 20° C. and a factor introduced later for the temperature effect as indicated by tests.

For determining atmospheric reaeration the rate of 0.0043 $V^{1.75}$ lb. per sq. ft. per day per p.p.m. undersaturation was applied to the surface area. The average $V^{1.75}$ was determined from Figure 3.

For determining the oxygen absorption rate from air bubbles, the bubble absorption formula (Eq. 1) was used.

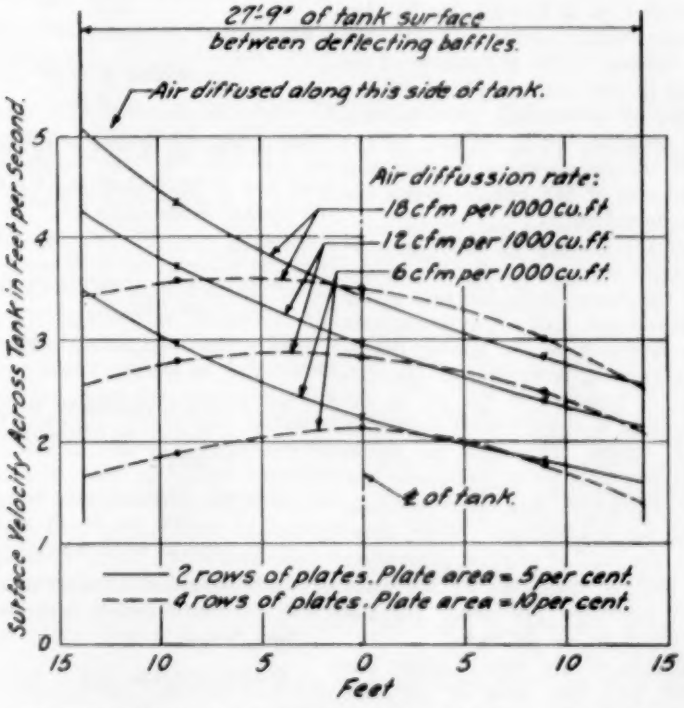

FIGURE 3.—Velocities across surface of spiral flow aeration tank.

The velocity of the water in the bubble zone in a spiral flow aeration tank increases as the water rises toward the surface. A computation on the oxygen absorption from bubbles indicated only a small difference obtained if the vertical velocity at half depth were used for the average rising rate instead of summing up the absorptions for parts of the rise to take care of the varying velocity. The depth to the diffusers divided by the sum of the average rising velocity of the water and the bubble slip, in feet per second, gave the bubble detention in seconds. This was used in the bubble formula (Eq. 1) to determine the oxygen absorbed.

The hydraulic model theory was used as a means for computing the oxygen absorption for depths other than 15 ft. to the diffusers. For example, consider geometrically similar aeration tanks. For the same length of channel a 1/12-scale model has 1/12 the water surface; 1/144 the water volume; 1/144 the volume of air bubbles in the water; and $\sqrt{1/12}$ the velocities of circulation. Then for this model tank the depth divided by the sum of the rising water velocity and upward slip of the bubble equals the bubble detention.

Since the relation of water to bubble volume is the same for the model as for the larger tank, the rate of air application per unit of water volume varies inversely as the bubble detention; corrected, however, for the difference of pressure of the air in the bubbles due to the different depths of the two tanks. Thus, for the model tank it was possible to determine the bubble detention and corresponding rate of air application. With these known, the rate of oxygen absorption could then be computed by the same method described previously for the 15-ft. depth to the diffusers.

A sample of the computations for channels with two rows of diffusers (diffuser plate area = 5 per cent) is shown in Table III for the basic tank of 15-ft. depth to the diffusers and for a 1/12-scale tank of 15-in. depth to the diffusers. Computations were actually made for tanks of four different depths with diffuser plate areas of 5 and 10 per cent. The oxygen absorptions, at three different rates of air application, were figured for various oxygen deficiencies and bubble sizes.

The bubble size was assumed to remain unchanged as the rate varied. Measurements of bubble diameters by Beck (12), to be discussed later, indicated that from a practical standpoint this was a reasonable assumption. By logarithmic plotting of the results, formulas were derived for each depth and these were combined into a formula applicable to any depth. The general formulas thus developed for clean water at 20° C. in circulating-type aeration tanks are as follows:

For diffuser plate area = 5 per cent:

$$A = \frac{0.0383\ H^{0.71}\ U^{Y}\ R^{X}}{d^{0.64}} \quad \ldots . (4)$$

For diffuser plate area = 10 per cent:

$$A = \frac{0.0262\ H^{0.77}\ U^{Y}\ R^{M}}{d^{0.70}} \quad \ldots . (5)$$

in which,

A = oxygen absorption, in p.p.m. per hour;

H = depth to porous plate diffusers, in feet;

U = oxygen deficiency for water, in p.p.m. at atmospheric pressure;

R = air diffusion rate in c.f.m. per 1,000 cu. ft. of water (free air at 60° F. and 29.3 in. Hg);

d = weighted average diameter of air bubbles, in inches;

$Y = {}^{1}/H^{0.1}$;

$X = 0.85/H^{0.03}$; and

$M = 0.90/H^{0.05}$

TABLE III.—Oxygen Absorption Computations for Water in 2-Ft. Length of Spiral Flow Aeration Channel (Diffuser Plate Area, 5 Per Cent; Water Temperature, 20°C.; Air Bubble Diameter, 0.1 in.; Oxygen Deficiency, 8 p.p.m.)

Air[1] per 1,000 cu. ft. (c.f.m.)	Rising Air Bubbles				Surface		Total Oxygen Absorption		
	Avg. Water Velocity + Upward Slip of Bubble (ft./sec.)	Rising Time (sec.)	Oxygen Absorption (%)	Oxygen Absorption (lb./day/1,000 cu. ft.)	$V^{1.75}$	Oxygen Absorp. (lb./day/1,000 cu. ft.)	(lb./day/1,000 cu. ft.)	(p.p.m./hr.)	From Surface (%)
(*a*) 15-Ft. Water Depth on Diffusers (Vol., 1,000 Cu. Ft.; Surface, 55.5 Sq. Ft.)									
6	1.38+0.75=2.13	7.1	16.0	23.7	4.62	8.8	32.5	21.8	27.3
12	1.92+0.75=2.67	5.6	13.2	39.0	7.16	13.6	52.6	35.2	26.9
18	2.08+0.75=2.83	5.3	12.5	55.5	9.43	18.0	73.5	49.2	24.5
(*b*) 15-In. Water Depth on Diffusers (1/12-Scale; Vol., 6.95 Cu. Ft.; Surface, 4.6 Sq. Ft.)									
32.4[2]	0.40+0.75=1.15[3]	1.09	3.65	28.8	0.54[4]	12.3	41.4	27.6	29.8
59.0	0.56+0.75=1.31	0.95	3.24	47.0	0.82	18.7	65.7	43.8	28.5
85.0	0.60+0.75=1.35	0.93	3.17	66.4	1.09	24.9	91.3	61.3	27.3

[1] Air free at 29.3 in. Hg (14.4 lb. per sq. in. abs.) and 60°F.; Wt. = 0.074 lb. per cu. ft.; 23.1 per cent oxygen.

[2] $6 \times \frac{7.1}{1.09} \times \frac{14.67}{17.65} = 32.4$

[3] $\sqrt{1/12} \times 1.38 = 0.40$

[4] $[(4.62)^{1/1.75} \times \sqrt{1/12}]^{1.75} = 0.54$

Oxygen absorption tests made by the Sanitary District in small tanks checked closely with the formula for a diffuser plate area of 5 per cent (Eq. 4). On the other hand, the formula for the 10 per cent plate area appeared to be about 5 per cent low in the small experimental tanks. Eq. 4 was retained as computed, but Eq. 5 was modified to give about 5 per cent higher results at 1-ft. depth but still retaining the computed rates at 15-ft. depth. Tests also indicated the absorption rate per p.p.m. oxygen deficiency to vary as 1.024^T, in which 1.024 is the temperature coefficient and T is the water temperature in degrees Centigrade. After modifying Eq. 5 and introducing the temperature coefficient, Eqs. 4 and 5 become, for a diffuser plate area of 5 per cent:

$$A = \frac{0.0243\ C\ H^{0.71}\ U^{Y}\ R^{X}(1.024)^{T}}{d^{0.64}} \quad . . (6)$$

For diffuser plate area = 10 per cent:

$$A = \frac{0.0175\ C\ H^{0.75}\ U^{Y}\ R^{N}(1.024)^{T}}{d^{0.70}} \quad . . (7)$$

in which the oxygen absorption coefficient, C, is also included. This has a value of 1.0 for clean water, but lower values for sewage and the mixed liquor of the activated sludge process. In Eq. 7, $N = 0.90/H^{0.04}$.

The formulas were derived from computations on bubble diameters of 0.1 to 0.2 in.; depths to diffusers of from 1 to 25 ft.; water temperatures of 8° to 25° C.; and dissolved oxygen of less than 50 per cent of saturation at atmospheric pressure. Therefore, their application should be restricted in use to a dissolved oxygen content in the water, in reference to atmospheric pressure, of less than 50 per cent of saturation. However, with this limitation they should still be applicable for

the conditions normally obtaining in the activated sludge process.

The formulas were worked out for a barometric pressure of 29.3 in. Hg (745 mm.), but apply closely for other barometric pressures if the air rate is converted to and used in the formulas as c.f.m. of free air at 29.3 in. Hg and 60° F.

At times it may be desirable to have formulas applicable over a wider range of oxygen deficiency. Those presented can be converted to accomplish this purpose under certain circumstances. For example, when air bubbles are of about 0.1-in. diameter and a relatively small amount of dissolved oxygen is present, about 25 per cent of the oxygen absorbed in an aeration tank is from the atmosphere for a diffuser plate area of 5 per cent and about 20 per cent for an area of 10 per cent. The percentage of oxygen entering solution from the atmosphere decreases as the dissolved oxygen increases and becomes zero when the dissolved oxygen equals saturation (referred to atmospheric pressure), after which, if the tank is of appreciable depth, oxygen continues entering solution, but from the bubbles only, with a loss from the surface. Therefore, the bubbles are an important factor influencing the rate of oxygen absorption, which must vary as the oxygen deficiency at a pressure somewhere between atmospheric and half depth.

For example, consider a spiral flow aeration tank of 26-ft. depth. If 25 per cent of the oxygen entering solution at zero D.O. is from the surface, by computation the total rate of absorption (with that from the surface varying as deficiency at atmospheric pressure and that from the bubbles varying as the deficiency at half depth) varies directly as the oxygen deficiency at 0.35-depth. For 20 per cent from the surface at zero D.O., the computed absorption rate varies as the oxygen deficiency at 0.37-depth.

The formulas can be converted to the first power of the oxygen deficiency at partial depth. For example, in a 26-ft. depth tank with a diffuser plate area of 10 per cent producing an average air bubble of 0.09-in. diameter, the oxygen absorption rate should vary about as the deficiency at about 0.35-depth. For water in this tank at 20° C. and an atmospheric pressure of 29.3 in. Hg, the D.O. saturation would be 9.0 p.p.m. at the water surface and 11.5 p.p.m. at 0.35-depth. The constant in Eq. 7 should be multiplied by $[(9.0)^{1}/_{26}^{0.1} \div 11.5]$ and the formula for 26-ft. diffuser depth and 0.09-in. air bubbles would be

$$A = 0.46\ C\ U_{0.35}\ R^{0.79}(1.024)^{T} \ldots (8)$$

in which $U_{0.35}$ is the oxygen deficiency in p.p.m., at 0.35-depth. Eq. 8 is applicable over the entire range of $U_{0.35}$ from zero to 100 per cent deficiency.

Eqs. 6 and 7, in which the oxygen deficiency of the water is for atmospheric pressure, are applicable for conditions normally occurring in the activated sludge process. However, conversion to a form such as that of Eq. 8 is often advisable for special tests and studies in a particular tank.

Effect of Diffuser Plate Area

This study has been confined to diffuser plate areas of 5 and 10 per cent in tanks twice as wide as deep, since the velocity tests in large tanks are available only for these particular diffusion areas. There are, however, many instances where larger diffuser plate ratios should be used. Therefore, it is important to have some knowledge of the effect of increasing diffusion area.

For a 15-ft. diffuser submergence the percentage of the oxygen absorption attributable to air bubbles, as computed by the method previously described, is approximately 75, 60, and 50 per cent for a 5 per cent plate area; 80, 70, and 60 per cent for a 10 per cent plate area, for 0.1- 0.2-, and 0.3-in. bubbles, respectively. The

smaller the bubble, the greater is the percentage of the total absorption from this source and the lower that from the atmosphere.

If air were diffused perfectly evenly over the entire area of a tank, the overturning and rising water currents would be eliminated and the bubble detention would equal the depth divided by the upward slip (0.75 ft. per sec.) of the bubble. Referring to Table III and assuming, for illustrative purposes, that it were possible to diffuse air evenly over the entire tank bottom, the bubble detention for 15-ft. depth would be 20 sec. and that for 15-in. depth, 1.67 sec. The bubble absorption would be increased as the detention raised to the 0.86 power (Eq. 1) and the surface reaeration would be eliminated. The over-all absorption would be improved over that for the 5 per cent plate area, increasing with air rate, amounting to about 135 per cent more for the 15-ft. depth at 18 c.f.m. per 1,000 cu. ft. and about 30 per cent more for the 15-in. depth at 85 c.f.m. per 1,000 cu. ft.

The larger the bubble size, the less is the value of increasing diffusion area. For example, for a 0.3-in. bubble, an analysis similar to the foregoing indicates that increasing the diffusion area from 5 to 100 per cent would result in a gain in over-all oxygen absorption of about 60 per cent for the 15-ft. depth at 18 c.f.m. per 1,000 cu. ft. and a loss of about 25 per cent for the 15-in. depth at 85 c.f.m. per 1,000 cu. ft.

It is to be concluded, therefore, that for spiral flow aeration tanks of depths such as normally used, the diffuser plate area should be as large as economical and practical; taking into consideration such factors as the costs of the diffusion system, the problems involved in the distribution of the air to the diffusers, and the limitations of diffuser area as related to the minimum circulating velocities necessary for adequate mixing. The smaller the air bubble, the deeper the tank, and the greater the B.O.D. loading, the more important it is to have as large an air diffuser area as economical and practical. For spiral flow aeration tanks, however, the rate of oxygen absorption will always vary as the rate of air application raised to a power less than 1.0, thus resulting in more power per pound of oxygen absorption as the rate of application increases in any particular diffuser system.

This study has been made on aeration channels in which porous plate diffusers are set in rows along one side close to the wall. Improved oxygen absorption efficiency should result, however, if the rows are farther from the wall and also spaced farther apart. This would result in lower velocities in the rising liquid just above the diffusers and, therefore, would mean a longer retention of the air bubbles. The result would be similar to increasing the diffuser plate area, but not as effective.

There are methods of increasing the time that the air bubbles are retained in the liquid other than by increasing the area over which the air is diffused. For example, if the velocities of the overturning currents are more than necessary to produce adequate mixing, these velocities could be reduced, thus improving absorption efficiency due to longer bubble retention, by diffusing a small part of the air near the wall on the side of the tank where the liquid is descending. In addition to slowing down the overturning velocities, oxygen from this part of the air would be well-absorbed due to time required to rise against the descending currents in the tank.

Improved knowledge of the mechanics of oxygen absorption by means of air diffusion should lead to future modifications and developments which will mean savings in the air and power necessary in the activated sludge process of sewage treatment.

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WATER POLLUTION ABATEMENT

The recent report to the President by the Commission on Intergovernmental Relations expressed the Commission's encouragement at the progress of some states in water pollution abatement. At the same time, the Commission is aware of the urgent need for greater attention at all levels of government to stream pollution as one of the Nation's most serious public health problems. It believes the state and national governments have a special responsibility for providing leadership and guidance to industry and local governments.

In the water pollution field, the Commission recommends that (a) states vigorously enforce existing water pollution abatement laws and that they expand and improve their legislation in this field; (b) as a stimulus to further action, the national government provide technical and financial assistance to state and interstate pollution control agencies; (c) study be given to the desirability of federal financial assistance, for a limited time, to cooperative programs for the construction of pollution abatement facilities; and (d) both national and state governments take steps to ensure that their own agencies and installations do not contribute to further stream pollution.

EXPERIENCE WITH SUBSURFACE SAND FILTERS *

By J. A. Salvato, Jr.

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In recent years there has been a great deal of research and engineering applied to the proper utilization of private sewage disposal and treatment systems (1)(2)(3)(4)(5)(6). This work has been necessary in order to control one of the major environmental sanitation problems associated with the scattered construction of homes where public sewers are not provided. During the same period only limited study has been given the design and construction of central sewage works for the smaller communities.

There is general agreement among sanitary engineers that properly designed, constructed, maintained and operated central sewage works are the best means for the collection and treatment of the sewage from a community. Although considerable progress has been made (8)(9), more effort must go into making possible the construction of more sewage works before and during the growth of a community. Public officials should actively discourage building construction in areas where the soil is unsuitable, until sewers connecting to a sewage treatment plant can be constructed. They should encourage by proper planning and other inducements construction in sewered or adjoining areas.

It is fruitless to argue the merits of central sewage works versus individual sewage treatment or disposal systems when the only practicable alternative for the immediate future is individual solution of the problem. However, the possibility and practicability of obtaining central sewage works, or preventing new building construction, should be thoroughly explored before construction of private systems are even considered.

When percolation tests indicate that the soil is too tight for the disposal of sewage by conventional means, bulletins and texts dealing with rural sewage disposal frequently have a notation at the bottom of the soil test interpretation table which reads "Unsuitable" or "Investigate sand filter trench" or "Consult with health department." Fundamental data on sewage disposal or treatment in tight soils are quite meager. Subsurface sand filter treatment systems, "transvap" disposal beds, tile field disposal systems in suitable earth fill, trickling filter systems, open sand filters, sewage farming, oxidation ponds and privies are suggested possibilities where the alternative is discharge of septic tank effluent into the roadside ditch or on the surface of the ground.

Filter Design

A typical subsurface sand filter design is shown in Figures 1 and 2. An application rate of 1.15 gal. (50,000 g.p.a.d.) of septic tank effluent per square foot of sand surface per day and a daily sewage flow of 150 gal. per bedroom are used in design. The specifications call for a clean sand having an effective size between 0.30

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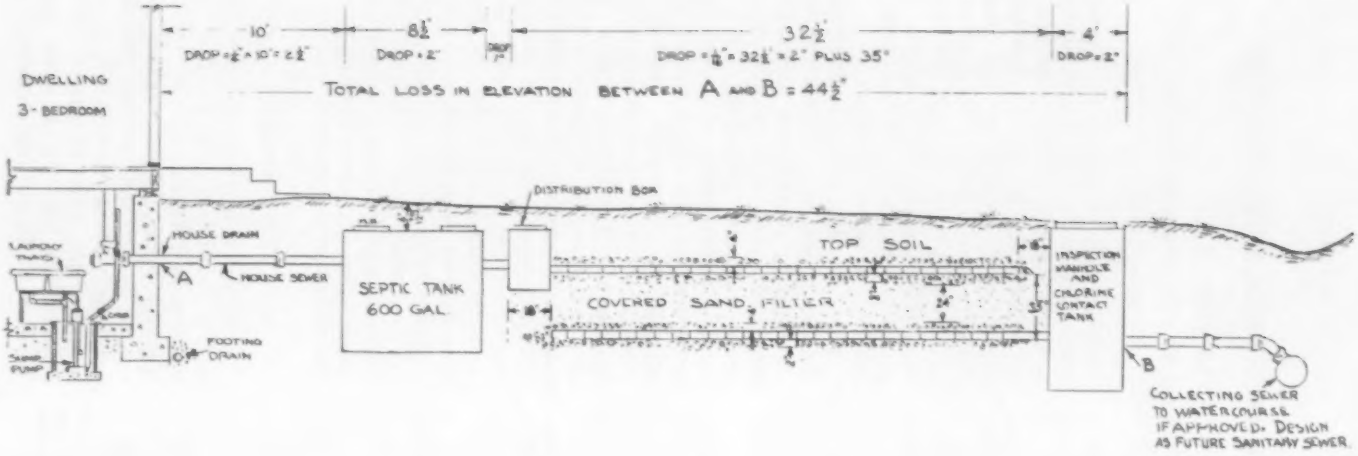
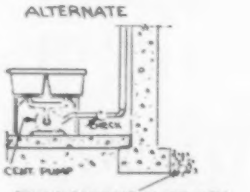
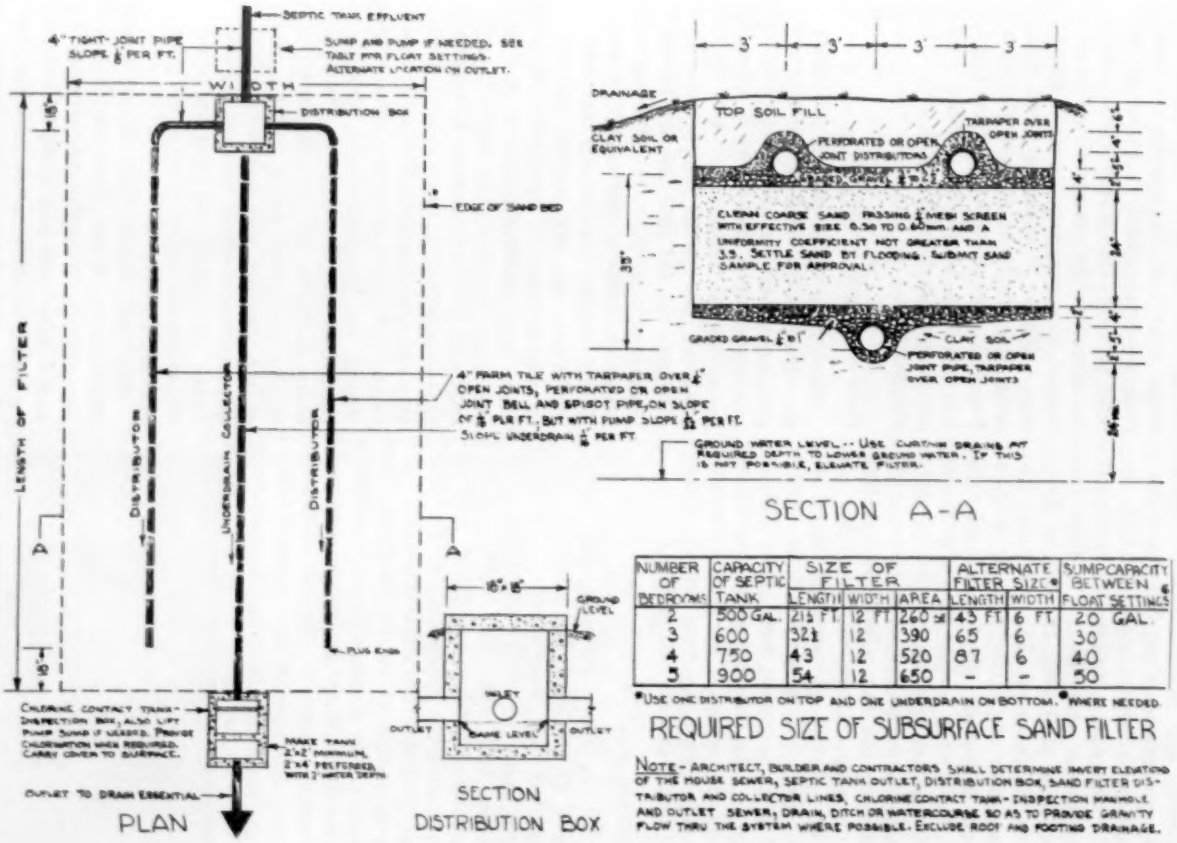



ALTERNATE
CHECK
CENT. PUMP
FOOTING DRAINAGE TO DRY WELL WHERE SOIL IS SUITABLE, OR TO A WATERCOURSE, DITCH, DRAIN OR STORM SEWER IF APPROVED BY THE LOCAL AUTHORITIES.

NUMBER OF BEDROOMS	LIQUID CAPACITY OF SEPTIC TANK*	AREA OF SAND FILTER*	REMARKS
2	500 GAL.	260 SQ. FT.	USE A CLEAN COARSE SAND, PASSING A ¼" MESH SCREEN, WITH EFFECTIVE SIZE 0.30 TO 0.60 mm. AND A UNIFORMITY COEFFICIENT NOT GREATER THAN 3.5. SETTLE SAND BY FLOODING. ESTABLISH ALL INVERT ELEVATIONS TO ASSURE GRAVITY FLOW IF POSSIBLE.
3	600	390	
4	750	520	
6	1100	780	
8	1500	1040	
12	2000	1560	

* IF A HOUSEHOLD GARBAGE GRINDER IS INSTALLED, INCREASE THE VOLUME OF THE SEPTIC TANK BY 50 PERCENT AND THE AREA OF THE FILTER BY 30 PERCENT. SOME AUTHORITIES RECOMMEND A 60 PERCENT INCREASE IN FILTER AREA.

FIGURE 1.—Typical subsurface sand filter layout.


SEPTIC TANK EFFLUENT
4" TIGHT JOINT PIPE SLOPE ⅛" PER FT.
SUMP AND PUMP IF NEEDED. SEE TABLE FOR FLOAT SETTINGS. ALTERNATE LOCATION ON OUTLET.
WIDTH
DISTRIBUTION BOX
EDGE OF SAND BED
LENGTH OF FILTER
DISTRIBUTOR
UNDERDRAIN COLLECTOR
DISTRIBUTOR
4" FARM TILE WITH TARPAPER OVER OPEN JOINTS, PERFORATED OR OPEN JOINT BELL AND SPIGOT PIPE, ON SLOPE OF ⅛" PER FT., BUT WITH PUMP SLOPE ½" PER FT.
SLOPE UNDERDRAIN ⅛" PER FT.
PLUG END
CHLORINE CONTACT TANK - INSPECTION BOX, ALSO LIFT PUMP SUMP IF NEEDED. PROVIDE CHLORINATION WHEN REQUIRED. CARRY COVER TO SURFACE.
MAKE TANK 2'x2' MINIMUM, 2'x4' PERFORATED WITH 2' WATER DEPTH
OUTLET TO DRAIN ESSENTIAL
PLAN
18"x18"
GROUND LEVEL
INLET
OUTLET
SAME LEVEL
OUTLET
SECTION DISTRIBUTION BOX
3' 3' 3' 3'
DRAINAGE
TOP SOIL FILL
CLAY SOIL OR EQUIVALENT
PERFORATED OR OPEN JOINT DISTRIBUTORS
TARPAPER OVER OPEN JOINTS
CLEAN COARSE SAND PASSING ¼" MESH SCREEN WITH EFFECTIVE SIZE 0.30 TO 0.60 mm. AND A UNIFORMITY COEFFICIENT NOT GREATER THAN 3.5. SETTLE SAND BY FLOODING. SUBMIT SAND SAMPLE FOR APPROVAL.
35"
GRADED GRAVEL ¼" TO 1"
CLAY SOIL
PERFORATED OR OPEN JOINT PIPE, TARPAPER OVER OPEN JOINTS
GROUND WATER LEVEL - USE CURTAIN DRAINS AT REQUIRED DEPTH TO LOWER GROUND WATER. IF THIS IS NOT POSSIBLE, ELEVATE FILTER.
SECTION A-A

NUMBER OF BEDROOMS	CAPACITY OF SEPTIC TANK	SIZE OF FILTER			ALTERNATE FILTER SIZE*		SUMP CAPACITY BETWEEN FLOAT SETTINGS
		LENGTH	WIDTH	AREA	LENGTH	WIDTH	
2	500 GAL.	21½ FT.	12 FT.	260 SQ. FT.	43 FT.	6 FT.	20 GAL.
3	600	32½	12	390	65	6	30
4	750	43	12	520	87	6	40
5	900	54	12	650	-	-	50

*USE ONE DISTRIBUTOR ON TOP AND ONE UNDERDRAIN ON BOTTOM. *WHERE NEEDED.

REQUIRED SIZE OF SUBSURFACE SAND FILTER

NOTE - ARCHITECT, BUILDER AND CONTRACTORS SHALL DETERMINE INVERT ELEVATION OF THE HOUSE SEWER, SEPTIC TANK OUTLET, DISTRIBUTION BOX, SAND FILTER DISTRIBUTOR AND COLLECTOR LINES, CHLORINE CONTACT TANK - INSPECTION MANHOLE AND OUTLET SEWER; DRAIN, DITCH OR WATERCOURSE SO AS TO PROVIDE GRAVITY FLOW THRU THE SYSTEM WHERE POSSIBLE. EXCLUDE ROOF AND FOOTING DRAINAGE.

FIGURE 2.—Typical subsurface sand filter section.

and 0.60 mm. and a uniformity coefficient not greater than 3.5. The Housing and Home Finance Agency (5) recommends clean filter sand having an effective size of 0.25 to 0.50 mm. and a uniformity coefficient not greater than 4.0. The Ohio Department of Health, Division of Sanitary Engineering (7), specifies a design rate of 50,000 g.p.a.d. with a sand having an effective size of 0.35 to 0.50 mm. and a uniformity coefficient not greater than 3.0 for subsurface intermittent sand filters. All consider the subsurface filter a last alternative, where soil is tight. A dosing device is necessary ahead of the sand bed where the total length of distributors is more than 200 to 300 ft. An alternating device feeding separate sections is usually recommended when the total length of distributors exceeds 600 to 800 ft.

Construction

To function correctly subsurface sand filters must be properly constructed and maintained. Undoubtedly many so-called subsurface sand filters bear only an accidental resemblance to the real thing, and in such cases the appearance of the effluent probably confirms this fact. It is necessary, therefore, that all concerned with the building of subsurface sand filters fully understand the construction details. Typical drawings fully dimensioned are essential aids, but these should not be followed blindly. The loss in head through the filter alone is 35 in. In the typical section the total fall from the house sewer to the chlorine contact tank-inspection manhole outlet is at least 44½ in. Unless this is taken into consideration before construction is started, pumping may be made necessary. Figure 3 shows a filter with sand bed, distribution box, distributors and chlorine contact tank-inspection manhole in place. Gravel and covering earth to grade will complete construction.

FIGURE 3.—Typical filter ready for gravel and earth cover.

Sand Size and Gradation

Since it is impossible to determine the effective size and uniformity coefficient of the sand by inspection, samples should always be analyzed. Local health departments may perform this service for the private individual. In the Erie County Health Department, N. Y., over 700 analyses have been made in the last five years. Except under particularly favorable conditions, the chances are that the local bank-run sand does not meet the filter sand specifications. It is then necessary to work closely with all local sand and gravel companies to encourage production of this special sand at a reasonable price. The success or failure of the program may rest largely on the cooperation received. Sand and gravel companies have met these problems by running analyses at the sand bank being worked, and at the washing and screening plant. Representative check samples are collected by health department representatives from stock piles at the plant and at the job.

Fair and Geyer (10) report that according to Allen Hazen, sands having uniformity coefficients between 1 and 5 will have practically the same hydraulic characteristics, provided the effective size of the sands is the same. However, if the high efficiency of intermittent sand filters to remove bacteria and to remove or oxidize organic

matter in sewage is to be maintained, the rate of filtration must be kept low —approximately one gallon per square foot of sand surface area per day. This will permit the biological coatings on the gravel and sand grains to undergo continuous stabilization.

Experience shows that whereas the specifications for effective size can be easily met, the specifications for a uniformity coefficient of less than 4.0 or 3.0 is difficult to meet unless special washing and extensive screening are employed. On the other hand, a uniformity coefficient of less than 4.5 or 5.0 can be met more easily.

Analysis of the limited data reported on here shows no clear relationship between uniformity coefficient or effective size of filter sand, and percent reduction in B.O.D., suspended solids, turbidity, oxygen consumed, bacteria or total nitrogen, nor with increase in nitrates and percent oxygen saturation. The uniformity coefficient varied between 6.1 and 2.6; the effective size varied between 0.23 mm. and 0.36 mm. The filters studied were designed for a filtration rate of 1.15 gal. per square foot per day, and as nearly as can be determined the sand beds were not overloaded. In view of the work done by Allen Hazen, the results reported here and the lack of substantiating data to the contrary, more stringent specifications than effective size 0.25 to 0.5 mm. and uniformity coefficient of less than 4.0 do not seem justified.

Sand Filter Effluent

It is sometimes stated that because sand filter effluent is usually well nitrified, the growth of aquatic plants is stimulated. The subsequent death and decay of plant life causes odors and unsightly conditions. This is a generalization which is only sometimes correct. Actually many of the reasons for algal blooms are not clearly understood.

It does not necessarily follow that the supply of nitrogen from filtered sewage alone determines the growth of plant life. Other nutritional and environmental requirements must be met for prolific growths to take place. These include phosphorus, calcium, magnesium, boron and others, as well as high water temperatures and proper pH. In any case, drainage from soil, chemically fertilized or manure treated fields, as well as certain industrial wastes, can contribute as much or more food for plant growth than a well nitrified subsurface sand filter effluent. Bartsch (11) summarizes this point by stating "water everywhere is a potential culture medium for at least some kinds of algae. Surface waters naturally contain all kinds of nutrient elements needed for growth, some of which are used only in trace quantities."

In Erie County, New York, about 1,500 subsurface sand filters, in an area of 1034 square miles, have been installed over a period of almost five years. These treatment systems were designed in accordance with the standards given in this paper. They were installed under the general supervision of the health department sanitary engineers and sanitary inspectors. The average cost of a typical system including the septic tank and contact tank was $500 to $600 for a one-family house. With 1,500 private systems installed, this represented an expenditure of about $825,000 to serve 5,250 persons. If this construction could have been confined to an area of one square mile where a contact tank and sump pump can be omitted, the cost would be reduced by $150 per dwelling. Another way of looking at this is that about 400,000 gallons per day of septic tank effluent, which would normally overflow onto the surface of the ground or into a watercourse, is receiving complete treatment.

TABLE I.—Typical Septic Tank and Subsurface Sand Filter Effluent

Determination	Sewage Effluent[1]	
	Septic Tank	Subsurface Sand Filter
Bacteria per ml., Agar, 36°C., 24 hr.	76,000,000	127,000
Coliform group M.P.N.	>110 million	150,000
Color (p.p.m.)	3.5	2
Turbidity (p.p.m.)	50	5
Odor[2]	4.5	1
Suspended matter[2]	3	1
pH	7.4	7.4
Temperature °C.	17	14
B.O.D., 5-day (p.p.m.)	140	4
D. O. (p.p.m.)	0	5.2
D. O. saturation (%)	0	52
Nitrogen, total (p.p.m.)	36	21
Free ammonia	12	0.7
Organic	12	3.4
Nitrites	0.001	0.02
Nitrates	0.12	17
Oxygen consumed (p.p.m.)	80	20
Chlorides (p.p.m.)	80	65
Alkalinity (p.p.m.)	400	300
Total solids (p.p.m.)	820	810
Susp. solids (p.p.m.)	101	12

[1] Median results, using 51 samples from septic tanks and 56 from filters.

[2] 1 = very slight, 2 = slight, 3 = distinct, 4 = decided, 5 = extreme.

Sampling

In this study, 51 samples from septic tanks and 56 from subsurface sand filters at 19 establishments were examined. The determinations made and typical results are shown in Table 1. The places sampled included three children's summer camps, one elementary school, five motels, two private homes, three restaurants, two small housing developments, two trailer camps and one factory. Two units were put in operation in 1950, five in 1951, eleven in 1952 and one in 1954.

All samples were grab samples collected between 9:30 AM and 11:00 AM on a Wednesday or Thursday and were delivered to the laboratory by noon. Examinations were made in accordance with "Standard Methods."

Operation of subsurface sand filters

The data for B.O.D., suspended solids, turbidity, oxygen consumed, and nitrogen removal, and increase in nitrates and dissolved oxygen saturation were plotted to determine any noticeable relationships between these values. It was observed that the per cent reduction in the sum of ammonia and organic nitrogen varied directly with the increase in the sum of nitrite and nitrate nitrogen. Free ammonia in the septic tank effluent was reduced from a median value of 12 p.p.m. to 0.7 p.p.m. and the organic nitrogen content was reduced from 12 p.p.m. to 3.4 p.p.m. The nitrites were increased from a median of 0.001 p.p.m. to 0.02 p.p.m. and the nitrates from 0.12 p.p.m. to 17 p.p.m. As is apparent, excellent nitrification was obtained. Significant relationships between other constituents were not apparent. Typical efficiencies of subsurface sand filters are given in Table II. Per cent removals of B.O.D. and suspended solids are given for 45 filters by Figure 4.

A statistical frequency distribution study and graphical analysis of the data showed that 50 per cent of the septic tank effluents, that is, those in the middle quartile, had a B.O.D. of 70 to 215 p.p.m. and a suspended solids of 60 to 200 p.p.m. The filter effluent results in the middle quartile had a B.O.D. of 2½ to 11 p.p.m., a suspended solids of 6 to 22 p.p.m., a nitrate content of 6 to 22 p.p.m., and a dissolved oxygen concentration of 3.3 to 7.6 p.p.m. with a per cent saturation of 32 to 70 per cent. The study also showed that 90 per cent

TABLE II.—Typical Efficiencies of Subsurface Filters[1]

Determination	Per Cent Reduction
Bacteria per ml., Agar, 36° C., 24 hr.	99.5
Coliform group: M.P.N. per 100 ml.	99.6
B.O.D., 5-day (p.p.m.)	97
Susp. solids (p.p.m.)	88
Oxygen consumed (p.p.m.)	75
Total nitrogen (p.p.m.)	42
Free ammonia	94
Organic	72

[1] Effluent will contain 5.2 p.p.m. dissolved oxygen and 17 p.p.m. nitrates.

of the time the suspended solids in the filter effluent was less than 37 p.p.m. and 90 per cent of the time the B.O.D. in the filter effluents was less than 21 p.p.m. The turbidity in the filter effluent was less than 14 p.p.m. 75 per cent of the time and less than 33 p.p.m. 90 per cent of the time.

Study of the data revealed an apparent contradiction as to dissolved oxygen content. One sand filter serving a motel was inadvertently completely covered with tarpaper before being covered with earth. Two samples collected from this filter were 31 and 60 per cent saturated with dissolved oxygen. Another filter serving a development of 12 dwellings was covered with about 7 feet of tight clay soil. Seven samples were collected from this filter over a period of 2½ years. Dissolved oxygen was found in every sample with the saturation varying from 23 to 100 per cent. Of the 56 subsurface sand filter samples examined, only one did not contain any dissolved oxygen.

Chlorination treatment at the outlet of a subsurface sand filter was found to be extremely effective in producing an effluent of satisfactory bacteriological quality. Bacteria counts of less than 120 per ml. and coliform counts of less than 3.0 per 100 ml. were consistently obtained with a flash residual chlorine in the filter effluent of 0.3 to 2.0 p.p.m. after a design detention period of 15 minutes.

A field spot check of 70 of the 1,500 subsurface sand filters that had been in operation two to five years was made by members of the health department staff to learn of any operating difficulties. In only one case was a slight odor reported. There had been no difficulty with operation at any of the places and the point of discharge to the ditch or stream was clear.

During the five year study only nine of the more than 1500 subsurface sand

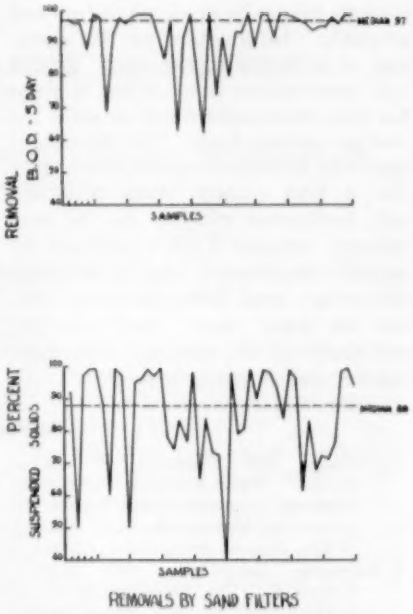


FIGURE 4.—Removals by sand filters.

filters were known to have failed. Causes of the failures were obvious on inspection. Annual inspection of residential septic tanks to determine the need for cleaning, and monthly sludge and scum reading of those tanks serving public or business places are indicated and warranted as a standard economic and public health preventive practice.

The question most frequently asked concerning subsurface sand filters is "How long will they last?" or "Why don't they plug up in a couple of years?" The same questions could be asked about subsurface tile field systems which are properly designed and maintained. Although many theories have been advanced, additional study and research is needed to provide satisfactory answers to these and related questions.

Summary

Subsurface sand filters can provide good treatment of settled sewage where the conventional type leaching

systems cannot be expected to function properly. Information on the operation of such filters is meager. Design and construction information is given for subsurface sand filters to serve the average private home. The laboratory and field investigations reported show that a high quality, clear, stabilized and inoffensive effluent can be consistently obtained from a properly designed, constructed and maintained subsurface sand filter treatment system for many years. More research and study of the mechanism of purification and clogging is needed.

Acknowledgment

All samples were collected by members of the Erie County Health Department rural sanitation staff. Their assistance and cooperation in obtaining essential field data for this report is sincerely appreciated. All examinations were made by the Erie County Laboratory under the supervision of William F. Millerschoen, Sanitary Chemist. The guidance received from Rachel Jenss, Sc. D., Director, Office of Biostatistics, in statistical analysis of the data is gratefully acknowledged.

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BIOCHEMICAL DEGRADATION OF SYNTHETIC DETERGENTS

II. Studies on the Relation Between Chemical Structure and Biochemical Oxidation

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The presence of increasing quantities of synthetic detergents in sewage and in some surface waters has become a matter of growing concern to many. The unique physical chemical characteristics of these surface active agents place the burden for their removal and the mitigation of their undesirable effects squarely upon the biological purification process of sewage treatment and of receiving waters. It is apparent that the extent or magnitude of the problems arising from a given synthetic detergent are largely a function of the biological persistence or biological "half life," so to speak, of the substance.

Preliminary studies (1) have disclosed that certain detergent types—notably the alkyl sulfates, sulfonated fatty acid amides and esters, and certain derivatives of low molecular weight polyethylene glycols—are subject to rapid biological stabilization. Those syndet types which are in general very slowly oxidized biochemically have been identified as the alkylaryl sulfonates, alkyl phenoxy polyethoxyethanols and, in general, derivatives of high molecular weight polyethylene glycols. Significantly, an ever increasing proportion of the syndets marketed in the United States are comprised of the more slowly oxidized molecular types. In fact, approximately 70 per cent of the synthetic detergents marketed at the time of this investigation could be categorized as being susceptible to a relatively slow rate of aerobic stabilization (1)(2).

The observed paradoxical behavior of certain detergent types such as the alkylaryl sulfonates and the polyoxyethylene derivatives strongly suggests that relatively minor changes or alterations in molecular structure may be responsible for rather widespread variations in susceptibility to biochemical oxidation (1). Moreover, consideration of those molecular types which are but slowly assimilated aerobically indicates that a certain few molecular constituents or groups may be primarily responsible for this relative biochemical inertness. It was the purpose of the research reported herein to establish information relating to the relationships which may exist between molecular structure and the susceptibility of a synthetic detergent to biochemical oxidation.

Experimental Procedure

The method employed in these studies was to follow the biochemical oxidation of various organic compounds by means of the Warburg apparatus and by the standard dilution B.O.D. technique (3). An acclimated activated sludge and a domestic sewage were used as seed in the B.O.D. determinations. The laboratory equipment was the same as used in the preliminary studies (1). However, the procedure for developing an accli-

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TABLE I.—Acclimation Schedules for Synthetic Detergents and Pure Organic Compounds

Day	Feed
(*a*) Synthetic Detergents	
1, 2, 3	Sewage + 10 p.p.m. syndet
4, 5	Sewage + 15 p.p.m. syndet
6, 7	Sewage + 20 p.p.m. syndet
8, 9	Sewage + 30 p.p.m. syndet
10, 11	Sewage + 40 p.p.m. syndet
12, 13, 14	Sewage + 50 p.p.m. syndet
48 hr. before use	Tap water + 50 p.p.m. syndet + 10 p.p.m. NH_3-N and 25 p.p.m. Na_2HPO_4
(*b*) Pure Organic Compounds	
1, 2, 3	Sewage + 10 p.p.m. substance
4, 5	Sewage + 20 p.p.m. substance
6, 7, 8	Sewage + 50 p.p.m. substance
9 to 14	Sewage + 100 p.p.m. substance
48 hr. before use	Tap water + 100 p.p.m. substance + 10 p.p.m. NH_3-N and 25 p.p.m. Na_2HPO_4

mated sludge was modified somewhat from that employed during the preliminary investigation.

The activated sludges employed in this phase of the investigation were developed and maintained on a once-daily feeding of domestic sewage and the particular substance under study. Sewage was filtered through cheesecloth to remove large solids and debris prior to feeding. All sludges were acclimated for a minimum of 14 days. The acclimation and feeding schedules were as given in Table I.

Aeration solids were allowed to accumulate to that concentration supported by a once-daily feeding. The only sludge wasted was that inadvertently carried over in decanting clear liquor from the aeration tubes after settling for 1 hr. At each feeding 1 l. of supernatant was wasted and the volume brought up to 1,500 ml. with Boston sewage. The appropriate concentration of the substance under study was then added and aeration commenced.

In preparing the sludges for use in the Warburg apparatus, mixed liquor was settled for 1 hr. and then all possible clear liquor was decanted. The settled sludge was then passed through cheese cloth and the suspended solids determined. Sludge was diluted with tap water so as to result in the concentration desired for use in the Warburg flasks. Activated sludge was treated as in the preliminary studies for use as a B.O.D. seed material (1).

The laboratory schedule was so arranged that the acclimation period for any given group of substances was generally 16 days ± 48 hr.

Experimental Results

The aerobic assimilation of a number of organic substances was studied. Compounds were selected which represented both the major synthetic detergent types as well as certain molecular constituents. In order to facilitate the quantitative analysis of biochemical oxidation data, each substance studied was employed as the sole source of organic carbon in both the B.O.D. and the Warburg analyses. Only materials of the highest possible degree of purity or of known chemical definition were selected.

Major Syndet Molecular Types

As noted earlier, resistance to biological degradation is associated with the following detergent types: alkyl benzene sulfonates, alkyl phenoxy polyethylene glycols, and certain aliphatic derivatives of polyethylene glycol. The principal limitation of this phase of the study was the availability of syndet types of a degree of purity such that their chemical constitution could be clearly established.

Three alkyl benzene sulfonates were studied, n-dodecylbenzene sodium sulfonate, kerylbenzene sodium sulfonate, and tetrapropene benzene sodium sul-

fonate. The n-dodecylbenzene sulfonate was obtained from the Atlantic Refining Company and was a pure chemical identity. The other two alkyl benzene sulfonates were supplied by the Procter and Gamble Company and represent middle portions of a narrow distillation cut taken from each of two reasonably well-defined commercial preparations.

Six other synthetic detergents also were studied, comprising one each of the following substances: alkyl sulfate, sulfonated fatty acid amide, sulfonated fatty acid ester, alkyl phenoxy polyethoxy ethanol, polyoxyethylene

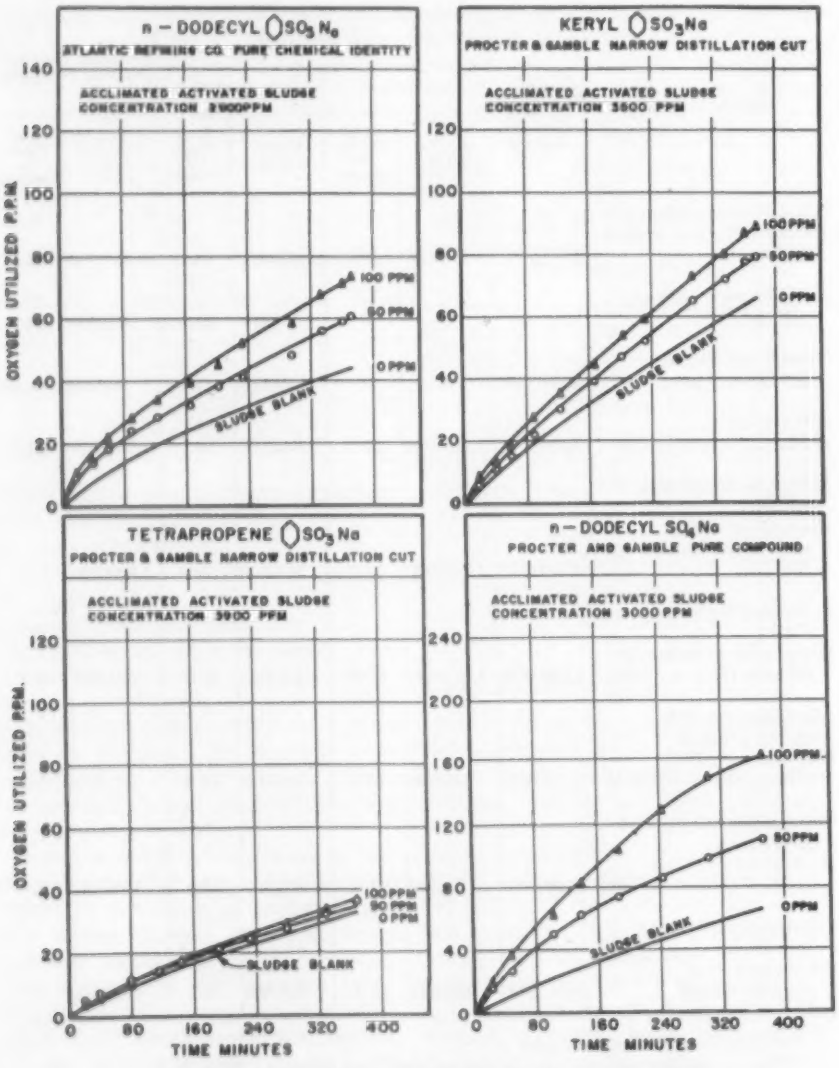
TABLE II.—B.O.D. of the Principal Syndet Molecular Types

Synthetic Detergent	Theor. Oxygen Demand for Complete Oxidation (p.p.m.)	5-Day 20° B.O.D.[1]				Biochem. Oxid. by Warburg Technique[2]	
		Sewage Seed		Accl. Act. Sl. Seed			
		B.O.D. (p.p.m.)	% of Theor. O_2 Demand	B.O.D. (p.p.m.)	% of Theor. O_2 Demand	O_2 Util. by Syndet in 6 hr. (p.p.m.)	% of Theor. O_2 Demand
Alkyl Benzene Sulfonates:							
n-dodecyl benzene sodium sulfonate	2,370,000	237,000	10.0	1,046,000	44.2	300,000	12.7
Keryl benzene sodium sulfonate	2,370,000[3]	0	0	535,000	21.6	240,000	10.1
Tetrapropene benzene sodium sulfonate	2,370,000[3]	0	0	81,000	3.4	40,000	1.7
Alkyl Sulfate:							
n-dodecyl sodium sulfate	2,280,000	1,307,000	57.2	1,362,000	59.7	930,000	40.7
Sulfonated Fatty Acid Amide:							
Oleoyl-N-methyl-N-sodium taurate (Igepon T-77)	2,780,000[3]	1,443,000	52.0	1,558,000	56.0	1,560,000	56.0
Sulfonated Fatty Acid Ester:							
Oleoyl ester of sodium isethionate (Igepon AP-78)	2,200,000[3]	1,315,000	59.8	1,460,000	66.5	990,000	45.0
Alkyl Phenoxy Polyethoxy Ethanol:							
Octyl phenoxy tetraethoxy ethanol (OPE-5)	2,370,000[3]	310,000	13.1	390,000	16.4	170,000	7.2
Polyoxyethylene Fatty Acid Amide:							
Hydrogenated Tallow amide (Ethomid HT/60)	1,950,000[3]	29,000	1.5	310,000	15.9	160,000	8.2
Polyoxyethylene Fatty Acid Ester:							
Stearic acid ester (Ethofat 60/60)	1,950,000[3]	226,000	11.5	316,000	16.2	190,000	9.7

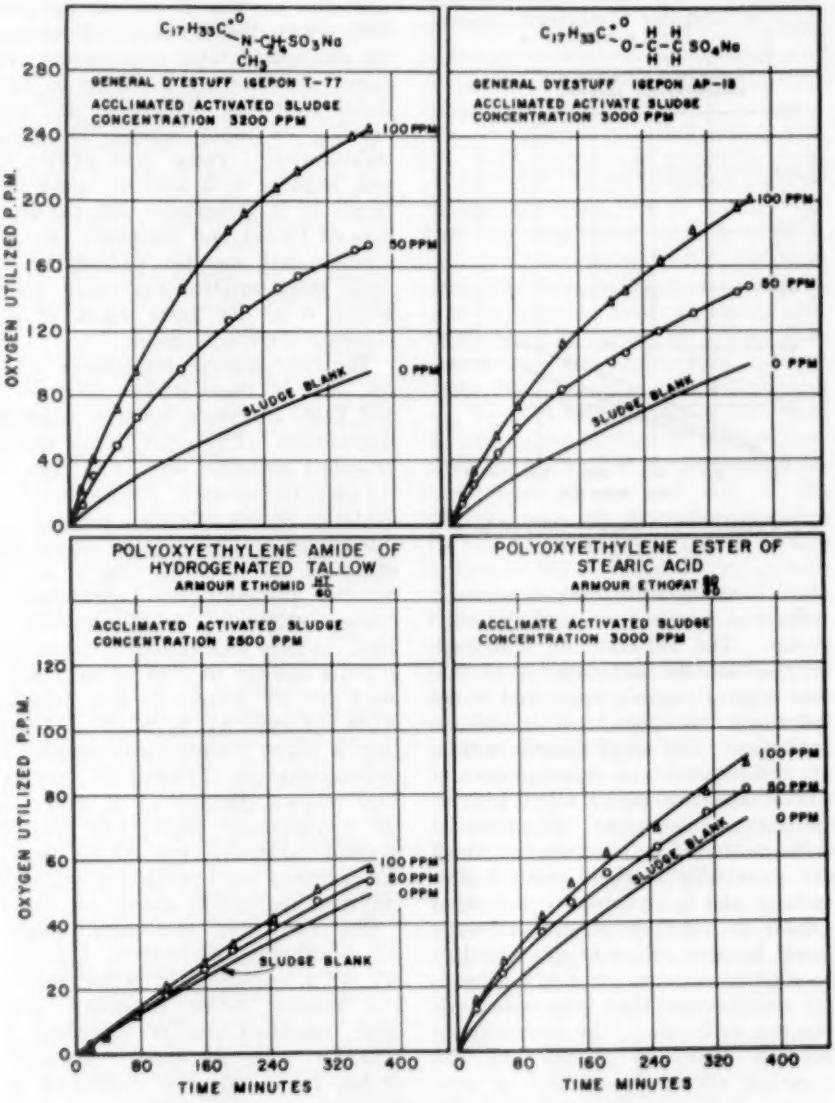
[1] By standard dilution technique.
[2] With acclimated activated sludge; summarized from Figures 1 through 9.
[3] Estimated.

fatty acid amide, and polyoxyethylene fatty acid ester. Of these only the alkyl sulfate was a pure chemical identity. The other substances were commercial preparations and were selected either because their chemical constitution was well defined or because they were the best available material representative of a particular detergent type. The alkyl sulfate was n-dodecyl sodium sulfate and was furnished by Procter and Gamble.

Both B.O.D. and Warburg data on oxygen utilization have been summarized in Table II. Warburg data are also presented in Figures 1 through 9. These data show the relative ability of both acclimated and nonaccli-



FIGURES 1-4.—Oxygen utilized in Warburg apparatus.



FIGURES 5–8.—Oxygen utilized in Warburg apparatus.

mated mixed cultures to utilize the major detergent types. In all but two cases—namely, those of n-dodecylbenzene sulfonate and n-dodecyl sulfate—the data represent the biochemical behavior of the isomeric and homologous mixtures of commerce.

The B.O.D. data in Table II and the Warburg data shown in Figures 1, 2, and 3 shed some light on the apparently paradoxical behavior of the alkyl benzene sulfonates observed in the preliminary studies. These data suggest that the biochemical oxidation of the

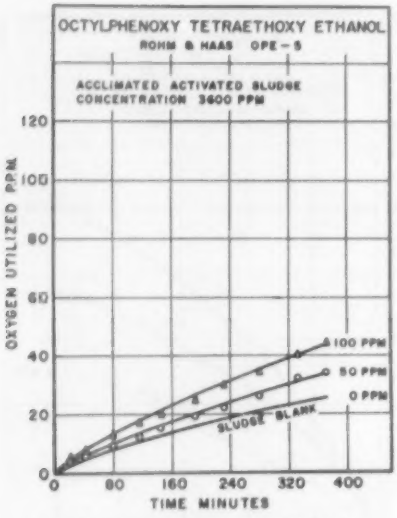


FIGURE 9.—Oxygen utilized in Warburg apparatus.

alkyl benzene sulfonates is strongly influenced by the nature of the alkyl group. The behavior of n-dodecylbenzene sodium sulfonate shows that this type of organic compound is not inherently resistant to biological assimilation. The keryl benzene sulfonate investigated was representative of one of the two major alkyl benzene sulfonates of commerce. This material is characterized by alkyl groups which are essentially straight chain hydrocarbons and is structurally somewhat similar to n-dodecylbenzene sulfonate. Keryl benzene sulfonate was found to be slightly more resistant to biochemical stabilization than was n-dodecylbenzene sulfonate. The tetrapropene benzene sulfonate represented the principal alkylaryl sulfonate of commerce. It is a complex isomeric mixture in which the alkyl groups are highly branched polymers of four propene molecules. The biochemical behavior of this substance presents a marked contrast to that of the first two alkyl benzene sulfonates. Resistance to biochemical oxidation appears to be a result of a highly branched alkyl group.

Again, as was found in the preliminary studies, the alkyl sulfates and the sulfonated fatty acid amides and esters were readily available as bacterial food and, therefore, are susceptible to rapid aerobic biological stabilization. These data (Table II and Figures 4, 5 and 6), when interpreted in accordance with the findings of Placak and Ruchhoft (4), indicate nearly complete assimilation of these three syndets has taken place within 6 hr. by 3,000 p.p.m. of acclimated activated sludge.

The octylphenoxy tetraethoxy ethanol used in these studies (Figure 9 and Table II) was a commercial grade preparation. The octyl group was a branched structure similar to that of the propene tetramer. The biochemical oxidation of this substance presents an interesting situation. Its degree of oxidation fell between that of keryl benzene sulfonate and tetrapropene benzene sulfonate. At the same time, both the rate and extent of oxidation appears similar to that of both Ethomid HT/60 (Figure 7) and Ethofat 60/60 (Figure 8), to which it bears only a slight resemblance; namely, a polyoxyethylene hydrophilic group. This raises a question as to where in the octylphenoxy tetraethoxy ethanol molecule oxidation was taking place; the branched octyl group, the polyoxyethylene hydrophilic group, or both?

The two high molecular weight polyoxyethylene derivatives, Ethomid HT/60, a hydrogenated tallow amide, and Ethofat 60/60, a stearic acid ester, exhibited similar bio-oxidative behavior with acclimated activated sludge, but acted quite differently in the presence of domestic sewage seed (Table II and Figures 7 and 8). Apparently, those organisms capable of utilizing the tallow amide were not as numerous in Boston sewage as were those capable of assimilating the fatty acid ester. Acclimation resulted in an approximately equal degree of utilization of either Ethomid HT/60 or Ethofat 60/60 by activated sludge.

Certain Organic Molecular Components of Syndets

The preceding experiments have demonstrated a number of interesting relationships between syndet structure and susceptibility to biochemical oxidation. Especially interesting is the apparent role which branching of an alkyl group plays in retarding biochemical oxidation. The manner in which the hydrophilic polyoxyethylene group affects oxidation remains obscure. It was felt that further experiments with substances resembling these two important molecular components would help to better understand the role they play in controlling biochemical oxidation.

Strictly speaking, the biochemical behavior of organic compounds resembling certain molecular constituents of synthetic detergents must be interpreted with reservation. Many of the physical and chemical properties of these organics may not be operative in or may be modified by the syndet molecule as a whole. In this respect there is the question of solubility. Some substances, such as the petroleum hydrocarbons, are only sparingly soluble in water and hence may accordingly modify the biochemical oxidations of activated sludge or of the B.O.D. test. On the other hand, by studying the behavior of a reasonably restricted group or homologous series of compounds, for example certain alkylbenzenes, so as to limit significant physical chemical variations, it is possible that important biochemical functions may be observed by contrast. The limited availability of high molecular weight polyethylene glycols and mono alkyl benzenes having more than four carbon atoms in the alkyl group of adequate chemical definition restricted the scope of this study.

Warburg data showing oxygen utilization in contact with activated sludge are shown in Figures 10 through 15, and B.O.D. data are presented in Table III. These data illustrate the biochemical behavior of certain synthetic detergent molecular components both in the presence of acclimated activated sludges and by non-adapted domestic sewage seed.

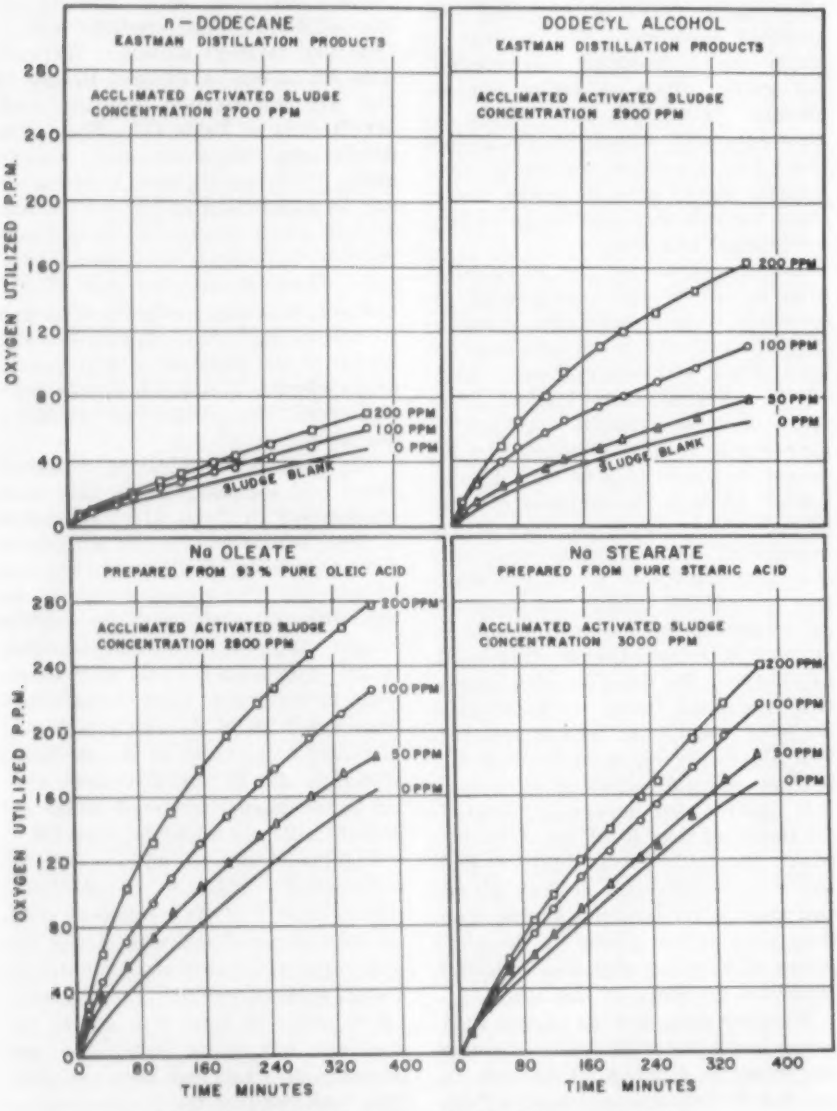
A 12-carbon-atom alkyl group is a commonly encountered molecular component (*viz.*, lauryl sulfate, dodecylbenzene sulfonate, etc.) Two 12-carbon aliphatics were studied—n-dodecane and dodecyl alcohol. Warburg data are shown in Figures 10 and 11 and are summarized together with B.O.D. data in Table III. These data demonstrate that a saturated, straight chain, 12-carbon aliphatic hydrocarbon can be assimilated under aerobic conditions, albeit slowly, by the microorganisms indigenous to domestic sewage. Opening up one end of the dodecyl molecule markedly increases its rate of oxidation. Apparently oxidation of the terminal methyl groups of n-dodecane is a much slower reaction than the subsequent oxidative changes.

The biochemical oxidation of sodium oleate and sodium stearate have been summarized in Table III. Oxidation of these two fatty acids by acclimated activated sludge is shown in Figures 12 and 13. The apparent rate of assimilation of oleic acid is slightly greater than that of stearic acid, other things being equal. This may be related to the double bond between carbons 9 and 10 in the oleate molecule. The rate and extent of bio-oxidation of sodium stearate and of dodecyl alcohol by acclimated activated sludge appears similar, as might be expected.

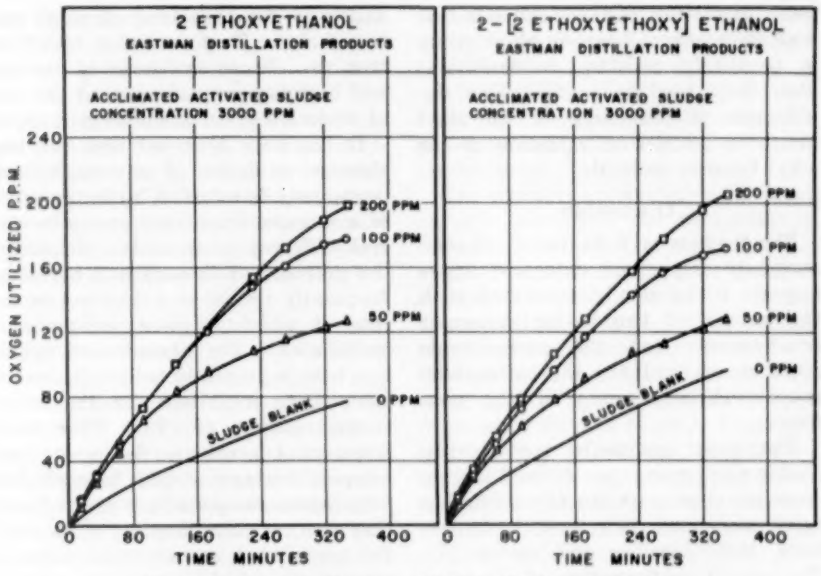
Figures 14 and 15 indicate that the biochemical oxidation of 2-ethoxyethanol and 2-(2 ethoxyethoxy) ethanol by acclimated activated sludge was both rapid and nearly complete during a 6-hr. aeration period. The biochemical behavior of these two ethoxy derivatives was quite surprising and contrary to what had been expected. This indicates that the oxygen atom or ether linkage in a low molecular

weight polyoxyethylene did not block its degradation.

The biochemical oxidative behavior of benzene and certain of its derivatives is summarized in Table III. Sodium benzene sulfonate was found to be markedly more susceptible to biochemical oxidation than was benzene. Apparently the presence of the sulfonate group materially alters the behavior of the benzene ring. This bio-oxidative activation was not observed with 2, 3, and 4 carbon atom side chains. In fact, the biochemical oxida-



FIGURES 10–13.—Oxygen utilized in Warburg apparatus.



FIGURES 14–15.—Oxygen utilized in Warburg apparatus.

TABLE III.—B.O.D. of Syndet Molecular Components

Substrate	Theor. Oxygen Demand for Complete Oxidation (p.p.m.)	5-Day 20° B.O.D.[1]				Biochem. Oxid. by Warburg Technique[2]	
		Sewage Seed		Accl. Act. Sl. Seed			
		B.O.D. (p.p.m.)	% of Theor. O_2 Demand	B.O.D. (p.p.m.)	% of Theor. O_2 Demand	O_2 Util. by Substrate in 6 hr. (p.p.m.)	% of Theor. O_2 Demand
n-Dodecane	3,480,000	98,000	2.8	279,000	8.0	120,000	3.5
n-Dodecyl alcohol	3,100,000	837,000	27.0	920,000	29.7	470,000	15.2
Sodium oleate	2,710,000	1,059,000	39.0	1,717,000	63.5	620,000	22.8
Sodium stearate	2,750,000	1,065,000	38.6	1,467,000	53.3	480,000	17.4
2Ethoxy ethanol	1,960,000	149,000	7.6	1,065,000	54.3	1,010,000	51.5
2(2Ethoxyethoxy)-ethanol	1,910,000	157,000	8.2	656,000	34.3	760,000	39.8
Sodium benzene sulfonate	1,290,000	34,000	2.6	960,000	74.5	500,000	38.8
Benzene	3,080,000	58,000	1.9	75,000	2.4	100,000	3.3
Ethyl benzene	3,170,000	88,000	2.8	84,000	2.7	260,000	8.2
n-Propyl benzene	3,200,000	72,000	2.3	81,000	2.5	25,000	0.8
n-Butyl benzene	3,600,000	455,000	12.6	499,000	13.9	200,000	5.6
t-Butyl benzene	3,600,000	11,000	0.3	12,000	0.3	20,000	0.6

[1] By standard dilution technique.
[2] With acclimated activated sludge.

tion of the alkyl benzene type of molecule was related to the nature of the alkyl group. The even-numbered ethyl and n-butyl alkyl groups are apparently more susceptible to oxidation than either the odd-numbered n-propyl or the highly branched tert.-butyl alkyl groups. These results are

most interesting, for they indicate that a straight chain, 3-carbon alkyl group is peculiarly resistant to oxidation; also, they tend to confirm this significance of branching of an alkyl group in restricting oxidation of the alkyl benzene molecule.

Discussion

The biochemical behavior of the commercially important detergent types appears to be closely associated with the nature of two major molecular constituents: (a) the hydrophobic alkyl group, and (b) the hydrophilic polyoxyethylene group of the nonionics.

The most commonly used hydrophobic alkyl groups are derived largely from two sources—naturally occurring fatty acids and petroleum hydrocarbons, both paraffins and oleins (5). The spatial configuration of the alkyl carbon chain is either essentially straight or highly branched. The size of these alkyl chains may range from 8 to 20 or more carbon atoms. Best detergency appears to be associated with those surface active agents in which the alkyl carbon chains average approximately 12 carbon atoms in size.

Polyoxyethylene, $C_2H_4\ (OC_2H_4)_x$, is the chief solubilizing group of the nonionic-type detergents (2)(5). Ethylene oxide may be readily condensed or polymerized with various hydrophobic groupings. Condensation of ethylene oxide is a complex reaction. Even under ideal conditions condensation reaction products are a complex mixture of varying length polymers. All that is possible commercially is to obtain a product having certain average or gross characteristics. These polyoxyethylene hydrophilic groups may contain from less than 5 to more than 20 units of ethylene oxide (5).

In retrospect, the biochemical inertness observed with certain of these detergents of commercial importance at the time of this study was found to be associated primarily with the high molecular weight polyethylene glycols and with the branching of alkyl carbon chains. To a somewhat lesser extent the chance synthesis of isomers and homologs may also retard the rate of oxidation of certain detergent types.

It has been observed that the biochemical oxidation of an organic compound may be retarded by the presence of a common functional group in several different compounds. Similarly, the presence of isomers and homologs frequently results in a decrease in the rate at which a given substance is assimilated. The phenomenon operative here is generally held to be one of competitive inhibition for the active enzyme centers (6)(7). Since most commercial synthetic detergents are complex mixtures of both isomeric and homologous compounds, it seems likely that many of them may not be as readily assimilated as are pure organic compounds which represent a given type of detergent. This was actually observed with the relatively slowly assimilated alkyl benzene sulfonates of commerce, but not with the readily oxidized alkyl sulfate type. The implication is that such inhibition or retardation is significant with the more stable substances, but not necessarily with the more readily assimilated materials in an acclimated sludge system.

The biochemical significance of branching in an alkyl group appears to be primarily a chemical phenomenon. According to Sexton (8), replacement of active hydrogen with CH_3, other alkyl groups, and halogens, often alters the chemical reactivity of the molecule either by blocking chemically reactive positions or by activating other positions. In this respect the substitution of methyl and possibly other alkyl groups for hydrogen in a hydrocarbon chain might very effectively block or retard oxidative degradation of that chain.

Certain physical chemical characteristics of a synthetic detergent may have a marked bearing on its susceptibility to biochemical oxidation. The seemingly paradoxical behavior of the

low molecular weight and the high molecular weight polyethylene glycols can be explained in part, at least, on physical chemical grounds. Increasing the size of the polyoxyethylene molecule results in an abrupt reduction of its lipophilic tendencies. This, together with increasing size, apparently results in a sharp decrease in the ability of the polyoxyethylene molecule to diffuse through cell membranes.

It has been seen that an acclimated sludge is capable of readily breaking the ethoxy ether linkage. Apparently diffusion through cell membranes falls off rapidly after the ethylene glycol molecule is increased in size beyond 3 to 5 moles of ethylene oxide. The very slow rate of oxidation observed with the higher molecular weight ethylene glycols could be accounted for by dispersed intracellular enzymes originating from lysed and dead cells. Such metabolic activity would be largely random in occurrence and even fortuitous in nature, and because of the extremely low enzyme concentration existing at any given time the observed rate of oxidation would be slight. Biochemically the ethoxy ether linkage is readily susceptible to microbial cleavage and yet physically only the smaller ether molecules can apparently reach the necessary enzyme centers in the cell.

It has been seen that the nature of the biological test media can markedly affect the apparent behavior of certain synthetic detergents. Because of this a number of conditions must be satisfied. Ample opportunity for acclimation of the biological medium is a fundamental requirement. At the same time, adherence wherever possible to conditions of diet and environment which are typical of sewage treatment practice or of receiving waters is essential. This would require, among other things, that the basic biological substrate should be a domestic sewage and that a significant acclimated population is one which includes the effect of daily reseeding with sewage organisms. Consideration also should be given to a schedule of gradual rather than abrupt adjustment to the syndet concentrations imposed by analytical and experimental requirements.

The biochemical oxidation of many organic substances can be influenced somewhat by the presence of other metabolites such as might be found in sewage (9). In addition, it is not unreasonable to expect that certain significant organisms may be relatively slow growers and that their development may be seriously limited through dilution by growth of other organisms and wasting of sludge. A situation such as this would appear to impose undesirable restrictions upon the biochemical oxidation of certain relatively resistant substances.

Summary and Conclusions

An investigation has been made of the relationship existing between chemical structure and the biochemical oxidation of the major commercial detergent types. Data were obtained for a selected group of molecular types which at the time represented the principal syndets of commerce. In addition, a number of pure organic compounds representing certain common components of detergent molecules were also investigated. The biochemical behavior of these substances was studied under conditions which represented biological sewage treatment and simulated the biological processes of receiving waters. The results of this investigation show the following:

1. The susceptibility of a synthetic detergent to biochemical oxidation, other things being equal, was found to be primarily a function of the nature of two molecular components; namely, the hydrophobic alkyl group and the nonionic hydrophilic polyethylene glycol group.

2. The alkyl benzene sulfonate type of molecule is not inherently resistant to biochemical oxidation. On the con-

trary, behavior of the pure chemical identity n-dodecylbenzene sodium sulfonate indicates that such a substance can be readily available as bacterial food.

3. Branching of the alkyl group markedly reduces the susceptibility of a synthetic detergent to aerobic assimilation. In fact, the relative biochemical inertness generally associated with the alkyl benzene sulfonates of commerce appears to be due primarily to branching in the alkyl group.

4. The low molecular weight polyethylene glycols were found to be readily susceptible to biological degradation. This is especially interesting because it shows that the ethoxyether linkage does not of itself block biochemical oxidation, as hitherto expected.

5. The biochemical inertness of the high molecular weight polyethylene glycols appears to be related to their physical characteristics. Apparently, only the smaller ether molecules can reach the necessary enzyme centers in the cell.

Acknowledgments

The research described herein was made possible by a grant from the National Institutes of Health, United States Public Health Service.

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Non-Member Meeting of Interest

Division of Water, Sewage and Sanitation Chemistry (American Chemical Society Annual Meeting) University of Minnesota, Minneapolis, Minnesota, September 12–14, 1955.

Industrial Wastes

REVISED CONCEPTS ON BIOLOGICAL TREATMENT*

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Biological methods of waste treatment have had a rather long history. Trickling filters have been used for over one-half of a century and the activated sludge process was developed about 40 years ago. During the intervening years there has been opportunity for fixation of ideas concerning the requirements and limitations of each of these, some justified and some unjustified.

During the past decade or two, our concepts have been altered radically concerning permissible loadings of B.O.D. on both trickling filters and activated sludge. Furthermore, it has been learned that so-called toxic materials such as phenols and formaldehyde can be adequately treated provided consideration is given to concentration and nutrition. These experiences illustrate the importance of questioning what may be considered fixed concepts from time to time to determine their validity in light of new knowledge and requirements. Certainly, the high rate trickling filter and high rate activated sludge process would never have found favor if nitrified effluents were a modern day requirement. Development of the B.O.D. test and an appreciation of its significance in relation to stream pollution control served as a basis for the acceptance of both these accelerated processes.

* Presented at 26th Annual Meeting, New England Sewage and Industrial Wastes Assn.; Bridgeport, Conn.; Oct. 28, 1954.

Specific Problems Related to Industrial Wastes

There is widespread belief that biological methods of waste treatment, particularly the activated sludge process, must be conducted under very closely controlled and well defined conditions to produce satisfactory results. For example, it is often inferred that the pH must be controlled within the range of 7 to 8, that radical variations in temperature are highly detrimental, and that the sludges must be fed daily to prevent self-destruction.

A great many industries produce wastes that do not fall into the so-called optimum pH range of 7 to 8. Nearly all operate on an intermittent basis which often allows wide fluctuations in temperature and prolonged periods of starvation to occur. The problem of starvation periods could be of considerable importance in industries that close down for 2- or 3-week vacation periods, or are confronted with shut-downs due to labor troubles. Not many industries are fortunate enough to have acid and alkaline wastes produced in sufficient quantities to yield a composite waste in the pH range of 7 to 8. Since purchase of acid or alkali for neutralization may be necessary, it becomes important to determine the extent of pH adjustment that is required. From an engineering viewpoint, it might be more economical to build a larger treatment plant and operate at a less favorable

pH level to avoid excessive neutralization costs.

It has been reported that supplementary feeding of carbohydrate matter such as glucose has been resorted to in order to maintain the activity of biological processes over weekend shutdown periods. Such a practice could be extremely expensive and because it consumes a natural resource, would certainly have to be shown that it was necessary.

In view of the foregoing, it was deemed desirable to obtain information relating to biological treatment of wastes along the following lines:

1. The influence of radical temperature fluctuations such as might occur under winter conditions.
2. The influence of pH
   a) at uniform levels
   b) at fluctuating levels
3. The significance of starvation periods.

Method of Study

The conventional activated sludge process using 1,500 p.p.m. of aeration solids was chosen for these investigations because it has been claimed by many to be less rugged than trickling filters. In addition, it lends itself more readily to small-scale laboratory studies, particularly where temperature control is a consideration.

Figure 1 presents a view of the equipment used in the studies. Five constant temperature baths, each equipped with four 2.5-l. capacity aeration tubes, allowed study of a wide range of variables simultaneously.

Cotton kiering liquor having a pH of about 12 was chosen to represent alkaline wastes and sulfite waste liquor with a pH of 1.2 was chosen to represent acidic wastes. Each waste was diluted with tap water containing 2.5 per cent of domestic sewage to yield a mixture with a 5-day B.O.D. of 565 or 800 p.p.m. and then neutralized to desired pH levels with sulfuric acid or lime. Sufficient amounts of the diluted wastes were fed at 12-hr. intervals to give B.O.D. loadings ranging from 47.2 to 93.6 lb. per 1,000 cu. ft. of aeration capacity. Nutritional requirements

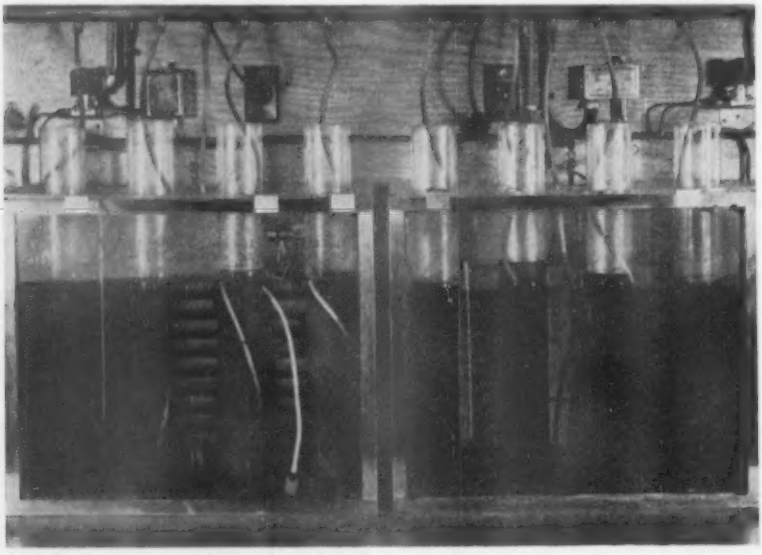


FIGURE 1.—Aeration units used in a study of variables affecting the activated sludge process.

were met by adding ammonium hydroxide, in the case of the acid waste, and ammonium sulfate, in the case of the alkaline waste, to yield a B.O.D. to N ratio of 20 to 1. Standard phosphate solution (KH_2PO_4) was added to yield a B.O.D. to P ratio of 150 to 1 when needed. The tap water containing 2.5 per cent of domestic sewage was relied upon to supply any trace element requirements.

All sludges used were developed from the industrial waste mixtures using an initial seeding of sewage organisms. When the sludges had grown to yield 1,500 p.p.m. of aeration solids, they were considered to be stabilized to their particular environment and intensive study of their behavior was begun.

Experimental Results

Temperature Fluctuations

Cotton kiering liquor adjusted to a pH between 7 and 8 was used in these studies. The influent B.O.D. was 800 p.p.m. and the B.O.D. loading was held at 66.7 lb. per 1,000 cu. ft. per day. The effect of twice daily temperature fluctuations between 10° and 20°C., 20° and 30°., and 10° to 30° C. was studied over a period of 23 days. The results of the studies are given in Figure 2 and show that the response to temperature change was immediate, regardless of whether the temperature increased or decreased. In most instances, the quality of the effluent was somewhat superior to that of the controls at the lower temperature and somewhat inferior to the effluent of the controls at the higher temperature. This is believed due to carry-over effects related to residual B.O.D. in the return sludge which was a result of the temperature maintained during the previous 12 hr. aeration period.

Following 23 days of comparing B.O.D. removals due to fluctuating temperatures, a study was made to determine the effect of a 20° C. temperature change on the rate of B.O.D. stabilization. The results of this study are shown in Figure 3 from which it may be seen that the rate of removal for a 10° C. sludge aerated at 30° C. approximated the rate of removal for a 30° C. sludge and the rate of removal for a 30° C. sludge aerated at 10° C. was similar to the rate for the 10° C. sludge. These data show that the response to temperature change is immediate.

pH Variations

Because of the great difference that temperature plays in governing rates of biochemical reactions, it was deemed advisable to make simultaneous studies on the effect of pH at 10°, 20° and 30° C.

The studies at pH levels above 8 were conducted using cotton kiering waste. Mixtures were made with tap water containing 2.5 per cent of domestic sewage to yield a diluted waste with a 5-day B.O.D. of 800 p.p.m. Portions of the feed mixture were then adjusted to pH levels of 10.5, 10, 9 and 7.5 and fed to the activated sludges to give B.O.D. loadings of 66.7 lb. per 1,000 cu. ft. of aeration capacity per day. In this series (Figure 4) pH levels of 10.5 and 10 were quite inhibitory at 10° C. while a pH level of 9 was only slightly inhibitory. At 20° C. a pH level of 10.5 was still quite inhibitory while at pH levels of 10 and 9 it was much less. At 30° C. there was little difference in the rate of removal, regardless of the starting pH.

The initial pH studies in the acid range were conducted with sulfite waste liquor. Mixtures were prepared with tap water containing 2.5 per cent sewage and the product had a 5-day B.O.D. of 565 p.p.m. Portions of the diluted waste were adjusted to pH levels of 5, 6, 7 and 8 and fed in quantities to give B.O.D. loadings of 47.2 lb. per 1,000 cu. ft. per day. In this series (Figure 4) pH levels of 5 and even 6 were very inhibitory to

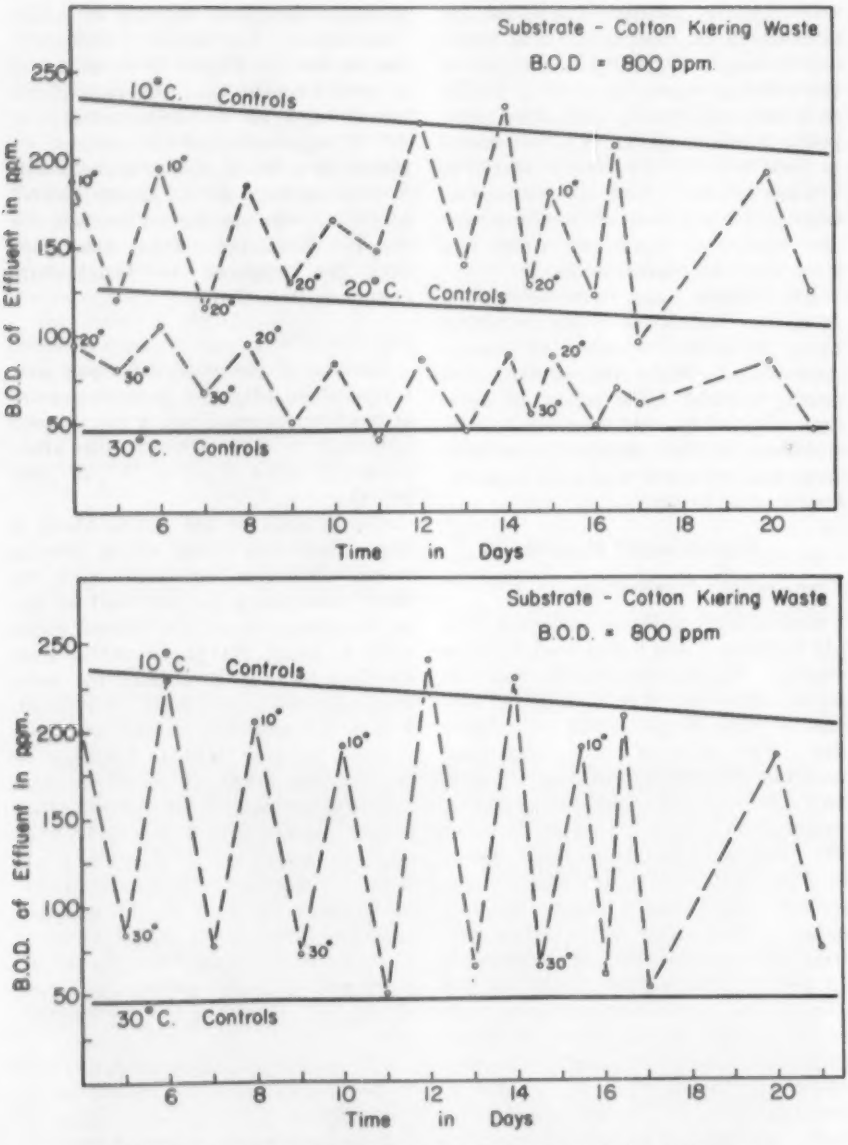


FIGURE 2.—Effect of temperature variation on B.O.D. of effluents.

rapid B.O.D. removal at 10° C. and showed considerable inhibition at 20° C. At 30°C., however, inhibiting effects were of little consequence.

Because the extreme inhibitory action of portions of the sulfite waste adjusted to pH levels of 5 and 6 did not seem logical, a study of pH variations during the course of a similar run were made. The results of this study (Table I) demonstrated that the falling pH levels were, undoubt-

TABLE I.—Change in pH of Sulfite Waste Liquor Aeration Mixtures with Time

Temp. °C	Aeration Time—Hours						
	0	1	2	3	5	7	10
10°	8.0	6.4	6.6	6.5	6.8	6.5	6.4
	7.0	5.9	6.3	6.1	6.0	5.2	5.6
	6.0	5.4	5.7	5.5	5.1	4.1	4.2
	5.0	5.0	5.0	4.8	4.5	3.0	3.6
20°	8.0	6.5	6.6	6.4	6.6	5.3	6.7
	7.0	6.2	6.4	6.3	6.2	4.6	6.2
	6.0	5.6	5.4	4.9	4.9	3.4	4.6
	5.0	4.8	4.3	4.1	4.0	2.7	3.5
30°	8.0	6.7	6.7	6.8	6.9	6.9	7.2
	7.0	6.4	6.5	6.4	6.5	6.5	7.2
	6.0	5.9	5.9	5.1	5.0	4.9	5.7
	5.0	5.5	5.3	4.9	4.6	4.6	5.0

edly, related to the unexpected behavior. The low buffering capacity of the waste was, apparently, unable to neutralize the stronger acid formed when the acid sulfites were converted to acid sulfates.

To demonstrate the behavior of a material having no sulfites or little strong acid forming substances when subjected to biological treatment under low pH conditions, cotton kiering waste was pretreated with sulfuric acid to destroy all the alkalinity. The waste was then mixed to produce a 5-day B.O.D. of 845 p.p.m. Portions were adjusted to pH levels of 4.5, 5, 6 and 7 and fed to the activated sludge to give B.O.D. loadings of 70.2 lb. per 1,000 cu. ft. per day. Studies of the rate of B.O.D. removal (Figure 5) showed only slight inhibition at pH levels of 4.5 and 5. Studies of pH changes showed ascending pH levels (Table II) in all cases as purification progressed. Thus, it may be concluded that the character of the waste under treatment will determine to a great degree the optimum pH to which a given waste should be adjusted for biological treatment.

In view of the findings obtained with

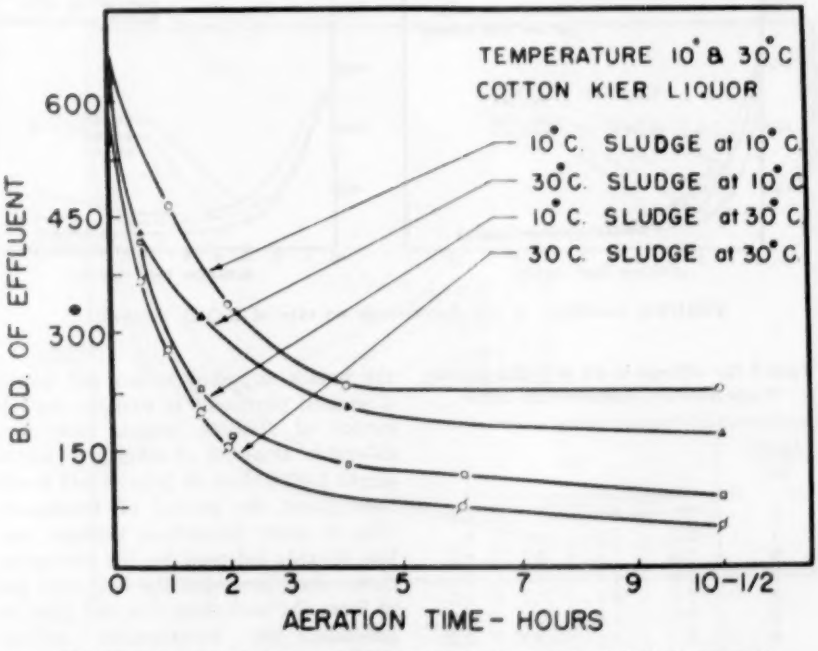


FIGURE 3.—Effect of temperature fluctuations on rate of B.O.D. removal.

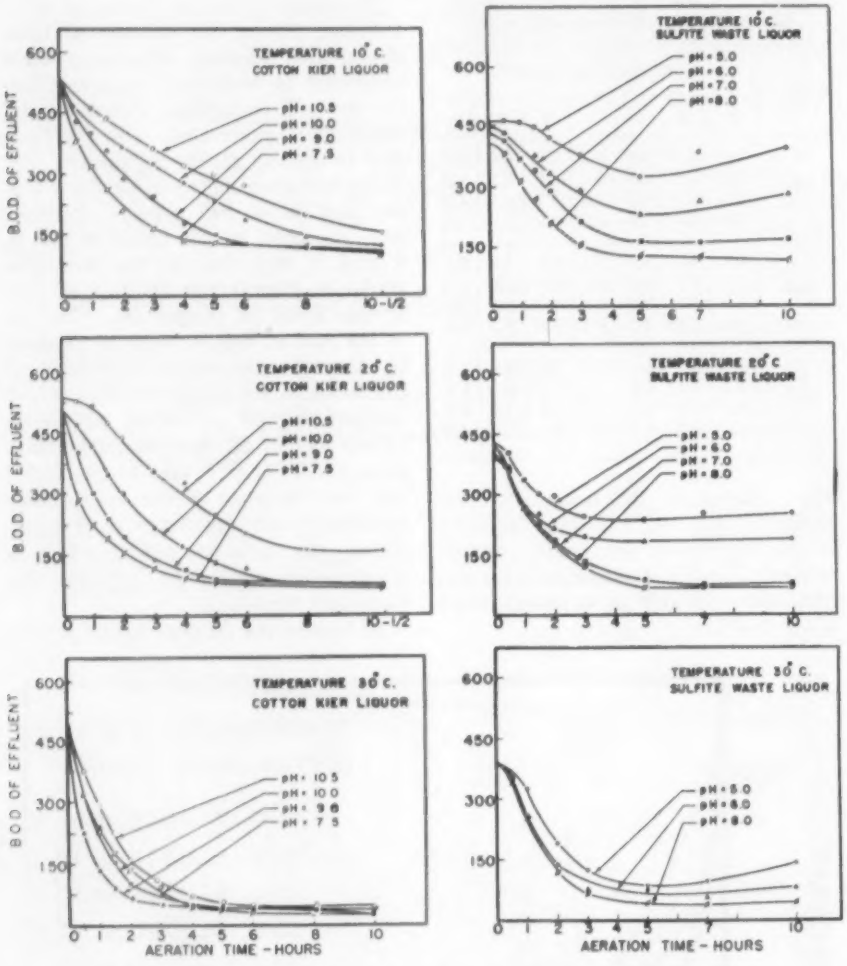


FIGURE 4.—Effect of pH fluctuations on rate of B.O.D. removal.

TABLE II.—Change in pH of Cotton Kiering Waste Aeration Mixtures with Time

Aeration Time (hr.)	pH			
0	7	6	5	4.5
1	7.3	7.3	6.1	6
2	7.5	7.5	6.7	6.7
3	7.5	7.5	6.9	7
5	7.7	7.7	7.1	7.3
7	7.9	7.8	7.4	7.5
9	8	8.1	7.3	7.4

the wastes adjusted to low pH levels, it seemed pertinent to explore the behavior of alkaline wastes with considerable amounts of alkalinity which might buffer them at definite pH levels throughout the period of treatment. This is quite important because carbon dioxide released by the biological forms combines with the hydroxyl ion to form the carbonate ion and then to produce the bicarbonate radical (HCO^-_3), constantly reducing the pH

TABLE III.—Effect of Alkalinity on Kier Liquor Effluent B.O.D. at pH 10.5

Days	Akalinity—p.p.m.			
	180	1650	2090	2410
0	54	52	54	53
1	115	101	80	47
2	105	97	95	76
3	137	135	98	47
4	83	76	65	59
6	56	62	50	65
9	51	46	39	44
11	55	57	49	52

level. In the studies conducted the alkalinity was increased to levels as high as 3,000 p.p.m. to buffer the pH at desired levels for periods far longer than would be expected in practice.

The results of studies conducted with various alkalinities at pH 10.5 are shown in Table III. It will be noted that about 5 days were required to acclimatize the sludge to the higher pH environment, particularly at the lower alkalinity levels. After operating under these conditions for 11 days, the pH of the waste was increased to 11 and the alkalinity adjusted to a maximum of 3,100 p.p.m. Effluent B.O.D. values during a 5-day run (Table IV) indicated that a high degree of B.O.D. removal can be obtained from wastes with initial pH values as high as 11.

Effect of Starvation

Starvation periods of two days, corresponding to weekend shut-down pe-

TABLE IV.—Effect of Alkalinity on Kier Liquor Effluent B.O.D. at pH 11

Days	Alkalinity—p.p.m.			
	1780	2165	2490	3110
0	55	57	49	52
0.5	105	69	70	86
1	108	94	78	92
2	95	74	63	88
5	87	86	73	72

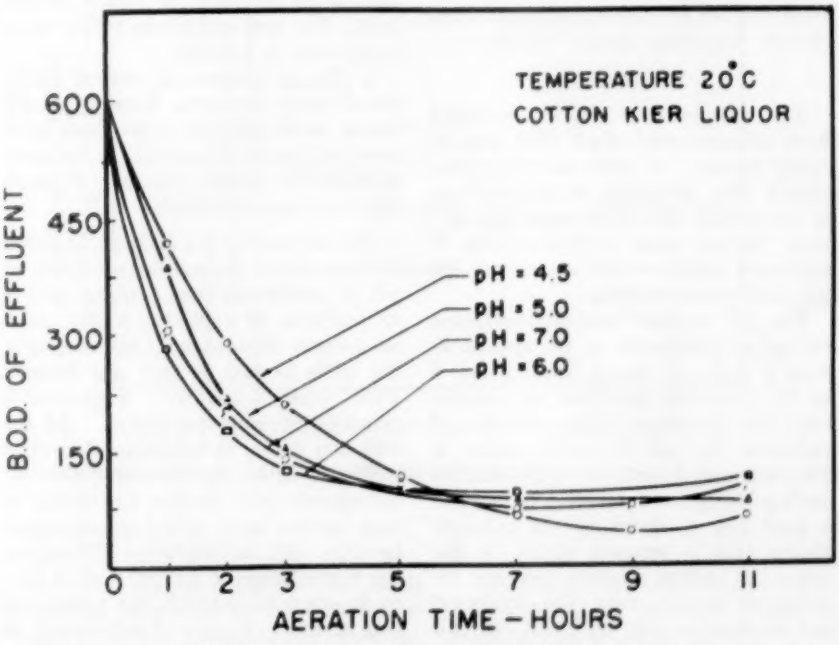


FIGURE 5.—Effect of pH on rate of B.O.D. removal.

riods, were found to have practically no effect on the purifying capacity of the sludges when the usual loads were resumed. For this reason attention was turned to longer periods of starvation such as might be caused by vacation or strike induced shut-downs. All sludges were kept under continuous aeration during the starvation period.

Two prolonged studies were conducted: the one with cotton kiering waste lasted for 22 days and the other with sulfite waste liquor lasted for 21 days. On resuming feeding, the waste was fed in the usual strength and the time required to produce effluents equivalent to those before starvation started was noted. Only 48 hr. were needed (Figure 6) for the sludges fed cotton kiering liquor to accomplish complete recovery of their original purification capacity and that the rate of recovering was independent of the B.O.D. loading. In the case of the sludges fed sulfite waste liquor (Figure 7), the sludges lost little of their original purifying power but recovered their former condition somewhat more slowly, requiring about 5 days.

Discussion

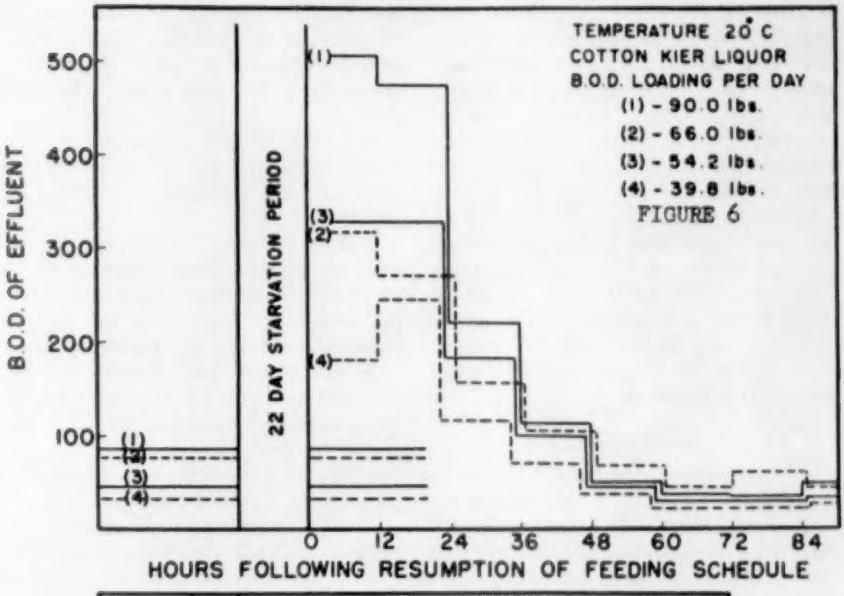
The temperature studies reported have substantiated much that was already known. In addition, they have shown that adaption to temperature is immediate and that rapid fluctuations do not cause a deterioration of activated sludge with respect to its physical characteristics.

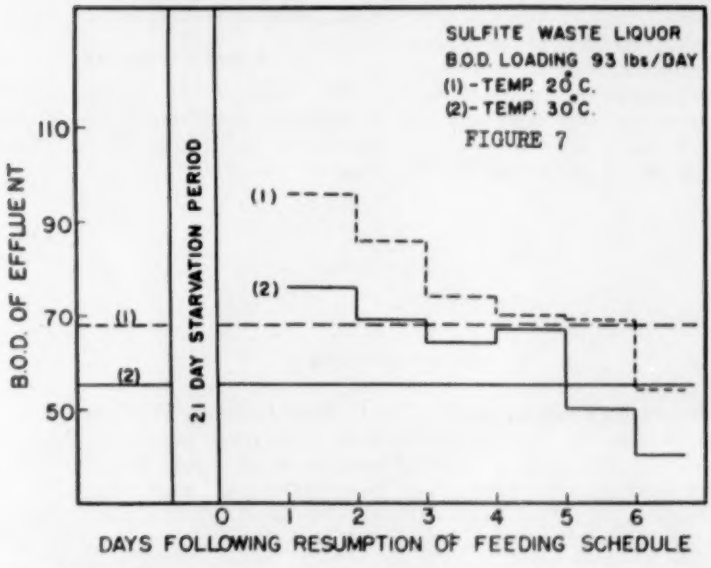
The pH studies have demonstrated biological treatment to be applicable over a wide pH range, from about 5 to 11, provided reactions do not occur that produce acids capable of reducing the pH to levels under 5. The normal course of pH changes during biological treatment is to yield a final pH of about 8. In alkaline wastes this is brought about by the union of carbon dioxide released by biological action with the hydroxyl and carbonate ions to form the bicarbonate radical. In wastes with pH levels of 5 or 6, free mineral acids are absent and the low pH is a result of weak organic acids or mixtures of such acids and their salts. Oxidation of the free acids produces carbon dioxide which is constantly removed by the aeration process and the pH rises as the concentration of free acids decreases. Oxidation of salts of organic acids, such as sodium acetate, results in the release of a basic anhydride (Na_2O) that combines with carbon dioxide to form sodium bicarbonate and buffer the mixture at a pH of approximately 8. The importance of these materials in recirculated effluents and return sludge should not be overlooked.

From the pH viewpoint, there would appear to be two possible types of organic wastes that are not amendable to biological treatment unless special precautions are taken to prevent a decreasing pH level. These are:

1. Wastes containing a weakly ionized acid which upon biological oxidation is converted to a highly ionized acid. The acid sulfites in sulfite waste liquor are an example.
2. Wastes containing neutral bodies which upon oxidation form relatively strong acids that are dependent upon a second group of organisms for their oxidation to carbon dioxide. Formaldehyde is an example.

The solution to the problem in either of these cases is continuous control of pH by automatic lime feeding devices or addition of sufficient buffer, such as sodium bicarbonate, to neutralize the acids as fast as they are formed. This may require considerable amounts of lime or buffer. If the difficulty is due to oxidation of neutral bodies to acids, the lime or buffer requirements will become negligible as soon as the acid oxidizing organisms become well established. Whenever the degradation of neutral bodies proceeds stepwise through the agency of two or more groups of organisms, it becomes extremely important to keep





FIGURES 6 AND 7.—Purifying ability of activated sludge following a starvation period.

the second group in a healthy condition. If they fail to keep pace with the acid formers, falling pH levels must be prevented by the addition of lime or buffer immediately; therefore, automatic control of pH at all times is imperative.

So much has been written about over-aeration of activated sludge and supposed deleterious effects on the

quality of the effluent produced that the impression has been created that activated sludge must be "spoon-fed" on the hour to keep it in a highly purifying state. Actually, under starvation conditions, a tremendous competition for food exists and a certain amount of cannibalism occurs resulting in a survival of the fittest. During the 21 and 22 day starvation periods discussed the aeration solids decreased from 1,800 p.p.m. to about 1,200 p.p.m., indicating a loss in population of only 33 per cent. The rapid recovery of the survivors is, of course, of greatest importance.

Conclusions

1. Adaptation of activated sludge to temperature change is immediate.

2. Temperature fluctuations at 12 hr. intervals between 10° and 30° C. (50°–86°F.) is not detrimental to sludge quality.

3. Biological purification of wastes with pH ranging from 5 to 11 can be accomplished by activated sludge, provided acids are not formed to depress the pH below 5.

4. The pH effects are a function of temperature. At low temperatures the effects are magnified. Thus, closer attention should be paid to pH control during the winter than the summer.

5. Levels of pH above 9 are definitely inhibitory at 10° C. and levels above 10 are definitely inhibitory at 20° C.

6. The decision concerning the degree of neutralization prior to treatment should be based on an engineering cost study comparing the cost of chemicals with larger plant facilities.

7. Automatic pH control is required when treating wastes that offer the threat of decreasing the pH below 5 due to acid formation.

8. Activated sludges may be starved for periods of at least 3 weeks without seriously impairing their purification capacity. Full purification capacity will be restored in 2 to 5 days after resumption of feeding at full load.

Acknowledgment

This investigation was supported by a research grant from the National Institutes of Health, U. S. Public Health Service.

CORRECTION

In the 1954 Literature Review II (THIS JOURNAL, **27**, 6; June, 1955) under the subject of Petroleum Processing, page 644, the reference to Mau (132) reads "Phenol removal ranged from 99.6 to 93.3 per cent for loadings of 25 to 300 p.p.m., respectively." It should read "Phenol removal ranged from 93.3 to 99.6 per cent for loadings of 25 to 300 p.p.b., respectively."

METHOD FOR DETERMINATION OF FREE FORMALDEHYDE

By Daniel K. Owens

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A method of determining free formaldehyde in waters which were turbid and highly colored was needed in connection with studies on stream pollution. The following modification of an old procedure was developed to meet this need. The method is rapid and sensitive and is not affected by turbidity, iron, organic matter, and color. It is easily adaptable for use in sewage work.

Samples of the Cape Fear river were found to be polluted with industrial wastes, dyes, organic matter, and colloidal clay. The method of Denigès (1) using Schiff's fuchsin bisulfite reagent was rejected because of its poor sensitivity and the necessity for preparing fresh standards daily. Since the quantity of formaldehyde present was on the order of 0.5 p.p.m., iodometric methods were unsatisfactory. The method suggested by Schryver (2) and later modified by Kersey, Maddocks, and Johnson (3) was found to possess the required sensitivity.

This method involves the formation of the phenylhydrazone of formaldehyde, the oxidation of this with potassium ferricyanide, and the development of an orange color by the addition of either sodium hydroxide or hydrochloric acid. Tannenbaum and Bricker (4) have shown that this reaction is time-sensitive, so that the time elapsing between the addition of the various reagents must be carefully controlled.

When this reaction was applied to the stream samples, it was found that iron in the water formed Prussian blue with acid development and ferric hydroxide with basic development, both of which interfered with the estimation of the color. The turbidity was removed with alumina cream, but it was found that this treatment also removed the greater part of the formaldehyde, perhaps by adsorption onto the surface of the alumina particles. Distillation was laborious and losses were experienced. These might be due to oxidation of the formaldehyde by substances present in the water.

Extraction of the color was attempted and it was found that the color was quantitatively removed by a single extraction with n-butanol. Turbidity, Prussian blue, and the dyes encountered in these samples were not extracted. The extracts possessed a slight turbidity because of suspended water droplets, but this was easily removed by centrifuging briefly.

Tannenbaum and Bricker (4) demonstrated that the base-developed color is more stable and more intense than the acid-developed color. The basic solution could not be extracted because an unbreakable emulsion was formed between the n-butanol and the aqueous solution. This does not occur in acid

FIGURE 1.—Absorption spectrum of color in n-butanol.

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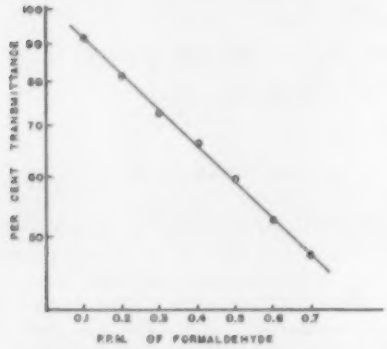

FIGURE 2.—Formaldehyde standard absorption curve.

solution; therefore, despite its inferiority, the acid method was employed.

The color in n-butanol was examined in a spectrophotometer using 1-cm. sample cells. The alcoholic color was shown to be identical with the aqueous color of Tannenbaum and Bricker, both having a well-defined absorption maximum at 520 mμ. The absorption spectrum of the color is shown in Figure 1.

The color follows Beer's Law up to a concentration of 0.7 p.p.m., as shown in Figure 2.

Reagents

1. Phenylhydrazine hydrochloride, 1 per cent aqueous solution. Dissolve 25 g. of reagent grade solid in warm water, make up to 500 ml., and filter.

2. Potassium ferricyanide, 5 per cent aqueous solution. This should be made fresh daily.

3. Hydrochloric acid, concentrated, reagent grade.

4. n-Butanol, reagent grade, aldehyde-free.

Procedure

To 2 ml. of phenylhydrazine hydrochloride solution in a separatory funnel are added 8 ml. of sample containing not more than 0.7 p.p.m. of formaldehyde, and the solution is allowed to stand for exactly 10 min. At the end of this time, 1 ml. of potassium ferricyanide solution is added and the solution is allowed to stand for exactly 5 min. At the end of this time, 4 ml. of concentrated hydrochloric acid are added, followed by 15 ml. of n-butanol. The funnel is shaken vigorously, the alcohol layer separated and centrifuged briefly to clarify it if necessary. The color is read at 520 mμ. against a reagent blank treated in the same manner as the samples 20 min. after the addition of the alcohol. The concentration of formaldehyde is determined by comparison with a suitable standard curve.

Interfering Substances

The only substance which could interfere with the determination is another aldehyde or combination of aldehydes. This poses no problem in water analysis because all results are reported in terms of formaldehyde (5).

Acknowledgment

The author gratefully acknowledges the cooperation of the staff of the Chemistry Section, North Carolina State Laboratory of Hygiene, in furthering this research.

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CONCENTRATION OF RADIOACTIVITY IN OXIDATION PONDS

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In the Southwest the use of oxidation ponds has become recognized as a useful means of secondary treatment of waste water. Local conditions, such as low rainfall and availability of land at relatively low cost, favor the use of this method. Equally important is the combination of high temperatures and much sunlight, and the resulting heavy algae growths which release oxygen in such amounts as to supplement greatly that which is dissolved from the atmosphere at the water surface.

The basic action of oxidation ponds involves the conversion of relatively complex organic compounds by aerobic bacteria to carbon dioxide; and this, in turn, is used by the algae. The net result is the conversion of organic matter to algal-cell substance accompanied by an accumulation of specific inorganic substances. This accumulation of specific inorganic materials and the fact that radioactive materials might be so concentrated, led to increased interest and research in oxidation ponds.

The oxidation pond investigations conducted at The University of Texas may be listed under four headings, as follows:

1. Classification of algae associated with oxidation ponds located in the Southwest.
2. Removal of radioactive isotopes through the action of algae and bacteria.
3. Survey of oxidation pond capabilities, including performance with domestic sewage and other liquid wastes, and use of non-conventional operating techniques.
4. Removal and concentration of algae and other particulate matter.

Investigational data are presented herewith of the removal of radioactive isotopes from a liquid waste when treated in an oxidation pond. Evidence based on laboratory studies indicates that significant amounts of radioactive isotopes may be temporarily transferred from the waste solution to the organisms by the complex mechanisms operative in oxidation ponds. The effects of biochemical processes, chemical precipitation, and ion exchange, in combination with the relatively long detention period, establish the value of oxidation ponds. The term "relatively long period" is used to distinguish between the mean detention time of a few days commonly used in oxidation ponds from that of a few hours normally required for the sedimentation of chemically produced flocculant matter. Oxidation ponds are also especially suited to receive variable concentrations of radioactivity without reducing the degree of removal.

Types of Algae

In oxidation ponds, the predominant organisms are the algae, which together with the bacteria and actinomycetes are known as "phytoplankton" if they are motile or freeswimming, and "phytobenthon" if sessile.

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TABLE I.—Algae of the Austin Region

Chaetophora incrassata
Coelospherium keutz
Conferva bombycina tribonema
Cosmarium cyclicum articum
Cosmarium meneghinii
Cosmarium turpinii
Cosmarium undulatum crenulatum
Cosmarium undulatum minutum
Closterium lanceolatum
Closterium monoliferum
Gonium pectorale
Herpostieron confervicola
Hyaletheca dissiliens minor
Hyaletheca dissiliens
Microspora stagnarum
Microsthamnion keutz
Mougeotia parvula
Mougeotia sphaerocarpa
Oedogonium macrandium
Oedogonium obsoletum
Oedogonium parisianum
Oedogonium pithopharae
Oedogonium varians
Oscillatoria formosa
Oscillatoria limosa
Palmodactylon varium
Pandorina morum
Pediastrum caudatus
Pediastrum tetra
Rhizorclonium hieroglyphicum
Scenedesmus abundans
Scenedesmus armatus
Scenedesmus biyuga
Scenedesmus caudatus
Scenedesmus obliquus
Spirogyra gradiata
Spirogyra grevillanea
Spirogyra groenlandia
Spirogyra hassallii
Spirogyra neglecta
Spirogyra particularis
Spirogyra punctata
Spirogyra setiformis
Spirogyra speeriana
Spirogyra stictica
Spirogyra ternata
Spirogyra varians
Stigeoclonium glomerata
Tetraspora gelatinosa
Tetraspora lubrica
Ulotrix oscillarina
Ulotrix zonata
Vaucheria terrestria
Zygnema cruciatum
Zygnema pectinatum
Zygnema pectinatum anomalum
Zygnema terrestre

Among the major groups of algae are the diatoms, desmids, blue-greens, sedentary greens, and pigmented flagellates. The genera and species of each may number in the thousands. Their growth is regulated by many chemical and physical factors associated with the water, such as pH, silica content, nitrates, carbonates, oxygen, phosphates, temperature, turbidity, and water currents. These factors, as well as the heterogeneity of the algal populations found in oxidation ponds, all have a bearing on the removal of radioactive materials in these basins.

Water samples containing algae were collected from creeks, pools and roadside ponds to determine the general and predominating types living under varying external environments. Identification of these organisms was greatly aided by a previous investigation (1). The wide variety of filamentous and non-filamentous algal forms which were identified in 1926 and 1953 are listed in Table I.

Another source of abundant algal growths adjacent to Austin was Mitchell Lake. Located near San Antonio, Tex., this lake was originally built to provide detention of the sewage of that city. In the past the lake has received varying amounts of settled sewage, digester overflow, and some storm drainage. Heavy fertilization has encouraged dense algal blooms to remain throughout the year. The algae most commonly found were *Oscillatoria*, but a more complete listing is given in Table II.

The different types of algae found to exist in oxidation ponds in Texas has been reported by Myers (2), and a summary of algae found in the sew-

TABLE II.—Mitchell Lake Algae

Date	Algae in Order of Predominance
1-11-53	*Oscillatoria formosa, O. splendida*; *Scenedesmus caudatus, S. obliquus, S. biyuga*; *Anabaena oscilarioidis*; *Closterium lanceolatum, C. monoliferum*; *Meriscopedia glauca*; *Golenkinia radiata*; *Cyclotella aperculata*; and *Cosmarium raegeliana*.
1-24-53	The same types as on 1-11-53, with a few colonies of *Chrysophaerellae longispina*.
2-9-53	The same types as before, plus a few *Nietzschiella*.
2-28-53	The same types as before, except a larger proportionate number of *Scenedesmus*.
4-13-53	Mainly *Oscillatoria*; a greater number and variety of *Scenedesmus*; more colonies of *Meriscopedia glauca*, *Actinastrum gracillium*, and a few *Beggiatoa alba* were present.
5-14-53	Mainly *Oscillatoria*; a greater number and variety of *Scenedesmus*; more colonies of *Meriscopedia glauca*, some *Actinastrum gracillium*, a few *Beggiatoa alba* were present.

age lagoons is given in Table III. The predominant algae at the time of the investigation were greens and blue-greens.

The types of algae in pilot-plant oxidation ponds, culture pans, and aquaria have been routinely checked over a period of about three years. Few genera and species preferentially appeared to thrive in the experimental oxidation pond. When oxidation ponds were first placed in operation *Euglena gracillis* was by far the predominant organism. After equilibrium was established the *Euglena* practically disappeared and were replaced by *Closterium*, several species of *Scenedesmus*, *Ankistrodesmus*, *Tetrastrum*, and *Tetraspora*, and lesser numbers of others. The only variance noted in types of algae in the pools occurred when heavy withdrawals required by the vacuum filtration experiments resulted in increased additions of waste water to the pools, which also decreased the detention period. This situation again encouraged the growth of *Euglena* and some filamentous types. In general, the predominate organisms in the cooler months appeared to be *Tetraspora*, *Oocystes* and *Scenedesmus*, whereas in the warmer months they were *Selenastrum* and *Scenedesmus;* however, the difference may not be significant. There was no correlation between types and numbers of algae found in the oxidation ponds and those found in Mitchell Lake. Repeated attempts to grow *Oscillatoria*, as found in Mitchell Lake, in the oxidation ponds proved unsuccessful.

TABLE III.—Summary of Data from Texas Sewage Lagoons

City	Date (1948)	Av. Flow (g.p.d.)	No. of Lagoons	Total Area (acres)	Pretreatment	Disposal of Effluent	Predominant Algae
Abilene	6/16	3,250,000	8	50	None	Irrigation	Unicellular and colonial greens
Alamo	6/3	30,000	1	2	Imhoff, trickling filter	Irrigation, considerable seepage and evaporation	Large spiral blue-green and colonial blue-greens
Boerne	6/15	—[1]	3	1	Imhoff, trickling filter	Irrigation	Green-flagellates, unicellular and colonial blue-greens
Coleman	6/16	—[2]	2	4	Imhoff	Irrigation	Unicellular and colonial greens
Comanche	6/8	275,000	2	4	Septic tank	Irrigation	Colonial greens
Decatur	6/10	100,000	3	3	Imhoff, trickling filter	Stream	Green flagellates, unicellular greens
Edinburg	6/3	800,000	1	26	Complete[3]	Drainage ditch[4]	Large spiral blue-green
Killeen	6/11	750,000	8	40	Primary settling only	Stream	Green flagellates, colonial blue-greens
Kingsville	6/5	—	1	6	None	Stream	Rod-shaped blue-green
Mathis	6/2	—	1	4	Imhoff	Stream, considerable evaporation and seepage	Colonial blue-greens
Premont	6/5	—	1	2	None	Irrigation, considerable seepage and evaporation	Green flagellates
San Antonio	6/15	45,000,000	1[5]	350	Portion treated in activated sludge plant; remainder untreated	Released to stream during high stream flow.	Rod-shaped blue-greens
Temple	6/11	2,000,000	1	12	Portion completely treated[3]; remainder, primary settling only	Stream	Small unicellular greens as *Scenedesmus*
Mission[6]	6/3	Lagoon of 2 to 3 acres dosed intermittently with raw cannery waste					Filamentous blue-green in shallow portion
Sherman[6]	6/10	13 lagoons in two series dosed continually with raw waste from shortening plant; waste mostly saponified fatty acids with excess alkali					Unicellular greens in later lagoons

[1] Designed for 2,500 population.
[2] 1,500 sewered population.
[3] Includes primary settling, trickling filter, and secondary settling.
[4] But only by seepage through levees.
[5] Lake Mitchell.
[6] Industrial waste lagoons.

TABLE IV.—Macroelements of Knops Solution

Salt	Mol. Wt.	Stock Solution		Final Medium	
		Conc. (g./l.)	Use (ml./l.)	Conc. (g./l.)	Molarity
$MgSO_4 \cdot 7\ H_2O$	246.5	50.0	50.0	2.50	0.0103
KNO_3	101.1	25.0	50.0	1.25	0.0124
KH_2PO_4	136.1	25.0	50.0	1.25	0.0092

Methods of Growing Algae

Flasks, open pans, aquaria, and small oxidation ponds were used during the different phases of adaptation of locally grown cultures to various environmental conditions.

Initially algae were grown in open 3-gal. pans for the purpose of (a) observing the difference in the rates of propagation, and (b) obtaining algae for use in laboratory experiments on the uptake of radioactive materials. Nutrients consisted of a modified Knops solution, urea, settled domestic sewage, laboratory waste, sodium citrate, and sodium bicarbonate. The chemical components of the Knops solution are shown in Tables IV and V. This solution is the conventional medium for *Chlorella*. It is prepared by dissolving 0.50 g. of purified Versene (ethylene diamine tetra acetic acid, EDTA) in 800 ml. of boiling water, cooling, adding stock solutions of the macroelements and 10 ml. each of microelements, adjusting the volume to 1,000 ml., and adjusting the pH by adding KOH as required. Tap and distilled water were both used; the analysis of the tap water is given in Table VI. The type of nutrient, except when excessive amounts of EDTA were used, did not appear to be as critical a factor as pH, amount of organic load, and temperature. Increased organic loads to an algae suspension brought about the most rapid change in the types of algae.

A number of 12-gal. aquaria receiving a synthetic substrate have also been used. A typical example is one in which three aquaria were connected in series and the liquid was transferred each day. B.O.D., as shown in Table VII, was reduced from 186 to 24 p.p.m. and from 70 to 18 p.p.m. for a synthetic substrate and a laboratory waste, respectively. These earlier experiments demonstrated that detention periods shorter than 20 days are possible.

Four oxidation ponds, three of 1,200-gal. and one of 3,000-gal. capacity, were constructed where they could be conveniently dosed from the Imhoff tank serving the Balcones Research

TABLE V.—Microelements of Knops Solution

Salt	Mol. Wt.	Stock Solution		Final Medium	
		Conc. (g./l.)	Use (ml./l.)	Conc. (g./l.)	Molarity
$CaCl_2$	111	8.35	10.0	0.0835	0.752
H_3BO_3	61.8	11.42	10.0	0.1142	1.847
$FeSO_4 \cdot 7\ H_2O$	278	4.98	10.0	0.0498	0.179
$ZnSO_4 \cdot 7\ H_2O$	288	8.82	10.0	0.0882	0.306
$MnCl_2 \cdot 4\ H_2O$	198	1.44	10.0	0.0144	0.073
MoO_3	144	0.71	10.0	0.0071	0.049
$CuSO_4{,}5\ H_2O$	250	1.57	10.0	0.0157	0.063
$Co(NO_3)_2 \cdot 6\ H_2O$	291	0.49	10.0	0.0049	0.017

TABLE VI.—Analysis of Tap Water

Designation	Magnitude
pH	9.7
Diss. solids	135 p.p.m.
HCO_3	21 p.p.m.
CO_3	16 p.p.m.
SO_4	21 p.p.m.
Cl	30 p.p.m.
NO_3	0.32 p.p.m.
Fe, total	0.03 p.p.m.
Si	6.4 p.p.m.
Ca	10 p.p.m.
Mg	9.7 p.p.m.
Na	8.8 p.p.m.
K	12.2 p.p.m.
Total hardness, as $CaCO_3$	65 p.p.m.
Non-carb, as $CaCO_3$	21 p.p.m.

Center of the University of Texas at which the Sanitary Engineering Research Laboratories are located. The Imhoff tank serves a population of about 400; but the sewage also includes wastes from chemical laboratories, pilot plants, and a large-scale primate experimental project. The discharges from the operation of these laboratories resemble many Atomic Energy Commission Laboratory wastes. The ponds can be operated in series or in parallel and provide any detention period at the designed dosage. The results obtained during the operation of these ponds (Table VIII) show that the effluent characteristics compare favorably with analytical data reported for other ponds operating in Texas.

Methods of Counting Algae

Several procedures for estimating the number of algae in a liquid suspension—including optical density, "packed" volume, and direct microscopic counting—were analyzed. The packed volume method is satisfactory when the types of algae and relative numbers remain the same. As compared with the direct microscopic count it is faster, but proved to be of little value in the oxidation pond experiments because the populations did not remain static. The packed volume is obviously a function of the shape and size of the cells. Consequently, changes in the predominant species might cause considerable error in the analysis, since flat cells compact more readily than round cells. Packed volumes were obtained by centrifuging 5-ml. Van Allen Thrombocytocrit centrifuge tubes for 20 min. at about 2,500 *G*.

Microscopic counting gave more satisfactory results and was used exclusively when counting mixed cultures. If the anticipated count was more than 500,000 per milliliter, the liquid was placed directly in the counting chamber without prior centrifuging. Algae suspensions requiring concentration were centrifuged in standard 15-ml. tapered-bottom Pyrex centrifuge tubes, with speeds and times as given for the volumetric tests. After a sample was centrifuged, approximately 13 ml. of supernatant was decanted. The concentrated algae were resuspended by diluting and mixing them with 3 ml. of distilled water. A count was then made, using a Levy-Hauser hemacytometer counting cell having rulings 0.05 mm. apart.

Radioactivity Uptake

Radioisotope investigations involved I^{131}, P^{32}, Sr^{89}, Cs^{137}, Ce^{141}, and mixed fission products. These were chosen either because they are products of fission or are used extensively in either medicine or research. Particular emphasis was placed on Sr^{89} because it is a product of uranium fission and is also an isotope which has

TABLE VII.—B.O.D. Reductions in Aquaria; 20-Day Detention (Three Aquaria in Series)

Nutrient	Average B.O.D.[1] (p.p.m.)			
	Raw	Effluent of Aquaria		
		No. 1	No. 2	No. 3
Synthetic substrate	186	46	36	24
Laboratory wastes	70	30	20	18

[1] 5-Day, 20°C.

TABLE VIII.—Summary of Analysis of Oxidation Ponds; 20-Day Detention

Sampling Point	Detention (days)	pH	B.O.D. (p.p.m.)	Organic N (p.p.m.)	B.O.D. Removal (%)
Infl. from Imhoff tank	0	7.1	106	20.2	—
Effluent from basin:					
No. 1	6	9.5	32	—	70
No. 2	13	10.2	27	—	74
No. 3	20	10.3	25	8.4	77

a very long biological half-life. The biological half-life values of the various radioisotopes used are: I^{131}, 180 days; P^{32}, 1,200 days; Sr^{89}, 3,900 to 18,000 days; Cs^{137}, 17 days; and Ce^{141}, 500 days. All of the isotopes used were obtained from the Oak Ridge installation of the U.S. Atomic Energy Commission.

Erlenmeyer flasks were generally used to initiate the isotope experiments; and following these, 12-gal. aquaria were used, except in the case of the mixed-fission products, which were added directly to the oxidation ponds.

Measurement of beta-radioactivity in samples was done with a Nuclear-Chicago Instrument scaler equipped with a thin-window Geiger-Mueller counting tube (3.1 mg. per sq. cm.); gamma emissions were counted on a beta-gamma scintillation counter. Liquid samples were prepared in duplicate, dried, counted, and reported as counts per minute per milliliter. It is possible that a slight difference in counting could have resulted from absorption of very low energy backscattered radiation in some of the heavier samples, but this was not significant because there was adequate consistency in all tests covering a wide range of sample weights. Radioactivity uptake by algae and associated material was determined by counting the activity in the algae suspension and by counting the radioactivity in the supernatant liquid of centrifuged samples. Unless otherwise noted, test samples contained about 2,000 counts per minute per milliliter of radioisotopes in the uncentrifuged material.

I^{131} Uptake

Radioactive iodine (Isotopes Division Catalog No. 53–F), as used in these experiments, is shipped as the iodide in a basic sodium sulfite solution. The maximum removal obtained in flask experiments was about 20 per cent, and the mean uptake over a period of two weeks was about 5 per cent. There was no difference in the amount of uptake between different algae concentrations. In the aquaria experiments, I^{131} uptake by algae and the other microscopic forms or precipitates was also about 5 to 20 per cent. The aquaria in these experiments were, in effect, small satellites of the oxidation ponds.

P^{32} Uptake

P^{32} (Isotopes Division Catalog No. 15A–P) contains about 0.025 mg. of stable phosphorus per millicurie. The uptake and release of P^{32} by algae followed a pattern similar to the increase and decrease of turbidity in agitated solutions, but different in other respects. The difference in uptake and release of P^{32} by algae-bacteria suspensions as compared to bacterial suspensions alone appears to be related not only to the amount of stable phosphorus but also to the usable organic material.

The usable organic material in this case is different for algae than for bacteria. The effect of usable organic material is shown in Figure 1, in which the percentage of P^{32} uptake is plotted against time, and the relative number of organisms remaining in a batch-type experiment after a given

period of time is shown. The B.O.D. and stable phosphorus in the initial solution containing only bacteria was considerably greater than in the solution containing algae and bacteria. The phosphorus (PO_4) in the solution which received only bacteria was about 10 p.p.m., whereas in that containing algae it was slightly less than 5 p.p.m. The curves in Figure 1 are used to illustrate that bacteria decrease in numbers, with an accompanying release of P^{32} from the dead cells, once the readily decomposable organic matter (B.O.D.) is significantly reduced. The algae, however, were able to survive after practically all of the 5-day B.O.D. was satisfied. In Figure 1 the B.O.D. of the solution containing bacteria was initially 200 p.p.m.; the B.O.D. of the algae-bacteria solution was only about 30 p.p.m. In solutions in which the initial B.O.D. and other characteristics of the system were more similar, the period of P^{32} detention was even more pronounced. The algae solution, which was used to compile the data for Figure 1, was taken near the effluent point of an oxidation pond. The very fact that algae, in growing, utilize carbon from different sources demonstrates the advantages of oxidation ponds over other biological systems in recovering P^{32}. Klein *et al.* (3), with controlled laboratory units, have shown that as much as 14 lb. of phosphorus per 100 lb. of influent B.O.D. may be used by *Euglena gracilis*. Bottom sediments naturally would have to be removed to prevent

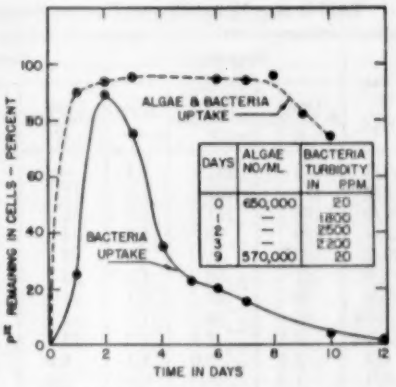
ALGAE & BACTERIA UPTAKE
BACTERIA UPTAKE
P32 REMAINING IN CELLS - PERCENT
TIME IN DAYS
DAYS | ALGAE NO/ML | BACTERIA TURBIDITY IN PPM
0 | 650,000 | 20
1 | — | 1800
2 | — | 2500
3 | — | 2200
9 | 570,000 | 20

FIGURE 1.—Metabolism of P^{32}.

uptake-release equilibrium conditions from occurring. Such condition would occur if the cell-detention time were not sufficiently long to effect decay.

Tests in which 12-gal. aquaria were operated as satellites of the various oxidation ponds substantiated smaller laboratory trials. The rate of P^{32} removal was primarily dependent upon the stable phosphorus competition and the rate of biological growth.

Cs^{137} Uptake

Algae grown in a variety of nutrients under batch and continuous-feed conditions were used in the examination of possible exchange behavior of cesium ions with algae. Cs^{137} (Isotopes Division Catalog No. 55–F) is a fission product and has a half-life of 37 years. The average uptake of Cs^{137} and its radioactive

TABLE IX.—Cs^{137} Uptake by Algae; 20-Day Detention, Continuous Feed [1]

Run No.	Nutrient	Algae (1,000/ml.)		Cs^{137} Removal (%)	
		Av.	Range	Av.	Range
1	Distilled water	0	0	3.0	0.7–9.3
2	Distilled water	950	185–1,800	2.3	0.3–5.6
3	Tap water	596	70–1,400	3.7	0 –8.0
4	Synthetic sewage	5,000	4,500–5,500	5.6	4.2–8.9
5	Settled sewage	0	0	3.2	0.4–8.6
6	Urea and distilled water	280	120–500	1.9	0.8–4.2

[1] Feed consisted of same liquid substrate initially used.

TABLE X.—Mixed-Fission Product Removal as Counted with a Geiger Mueller Tube [1]

Date	Pond No. 1			Pond No. 2			Pond No. 3			Over-All D.F.[2]
	Gross (c./m./ml.)	Centr. (c./m./ml.)	D.F.[2]	Gross (c./m./ml.)	Centr. (c./m./ml.)	D.F.[2]	Gross (c./m./ml.)	Centr. (c./m./ml.)	D.F.[2]	
1	2	3	4	5	6	7	8	9	10	11
12/1	358	257	1.4	—	—	—	—	—	—	—
12/2	274	222	1.3	17	12	1.4	—	—	—	—
12/3	163	111	1.5	31	21	1.5	2.5	1	2.5	358
12/4	120	90	1.3	34	22	1.6	7.2	4.0	1.8	90
12/7	60	33	1.8	22	16	1.4	9.5	6.0	1.6	60
12/8	41	36	1.1	23	18	1.3	9.1	6.2	1.5	58
12/9	30	27	1.1	24	19	1.3	10	7.2	1.4	50
12/14	15	14	1.1	16	14	1.1	11	7.8	1.4	46
12/18	9.1	7.4	1.2	13	11	1.2	13	8.3	1.6	43
1/5	4.1	3.9	1.1	6.2	5.9	1.1	8.0	5.6	1.5	64
2/4	1.2	—	—	1.2	—	—	1.0	—	—	—
2/18	2.9	—	—	1.0	—	—	0.5	—	—	—

[1] Relative counting geometry = 45 per cent; Tracerlab scaler and end-window type G.M. tube (3.1 mg. per sq. cm.)

[2] $\text{D.F.} = \frac{\text{Gross}}{\text{Centrifuged}}$.

[3] $\text{D.F.} = \frac{358}{\text{Col. 9}}$.

daughter Ba^{137} was less than 10 per cent under any condition tested. A typical example of results from a continuous-feed unit in which Erlenmeyer flasks contained different nutrients is shown in Table IX. The concentration of added salts, amount of nutrient, and number of algae were varied; but the change in uptake was insignificant. Data reported by Morgan and Myers (4) on experiments conducted with *Chlorella* and controlled salts also show that uptake of cesium by algae is insignificant. Traces of potassium ion in the exchange solution exert such a profound influence on the uptake of cesium ion from aqueous solution that the use of algae such as were used in these experiments is not practical. The relative concentration of potassium is high and traces of this element are everywhere present.

Mixed-Fission Product Uptake

An aged fission-product mixture (chlorides in weak HCl solution and equivalent to ORNL No. FP–P–1, having an age of one year or more) was also obtained. The activities were about 10 millicurie gross beta counts (10 per cent geometry) and 10^6 to 10^8 gross gamma counts (40 per cent geometry). Approximately 50 per cent of the beta particles were screened out with an aluminum absorber having a thickness of 80 mg. per sq. cm.

A 10-mc. shipment was placed in oxidation pond No. 1. After being mixed, samples indicated that there were about 360 and 160 counts per minute per milliliter as counted with a Geiger-Mueller tube and scintillation device, respectively. As shown in Tables X and XI, the least over-all decontamination factor resulting from dilution and sedimentation was 43 and 65 for beta and gamma emitters, respectively. Ratios of beta to gamma emitters in gross samples were very uniform, about 2.3, for all samples tested in the three different ponds. Centrifuged samples, however, showed that ratios of beta to gamma emitters fluctuated from 4.8 to 1.8, with an average of about 2.3.

Settled waste was supplied daily to the first pond, which was connected

TABLE XI.—Mixed-Fission Product Removal as Counted with a Gamma-Beta Scintillation Detector

Date	Pond No. 1			Pond No. 2			Pond No. 3			Over-All D.F.[2]
	Gross (c./m./ml.)	Centr. (c./m./ml.)	D.F.[1]	Gross (c./m./ml.)	Centr. (c./m./ml.)	D.F.[1]	Gross (c./m./ml.)	Centr. (c./m./ml.)	D.F.[1]	
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*
12/1	156	67	2.3	—	—	—	—	—	—	—
12/2	120	83	1.5	38	5	7.6	—	—	—	—
12/3	80	61	1.3	15	10	1.5	2.5	—	—	—
12/4	56	49	1.1	18	12	1.5	4	1	4.0	156
12/7	27	23	1.2	9	6	1.5	4.3	2.0	2.0	78
12/8	19	16	1.2	10	7	1.4	4.0	0.8	4	195
12/9	14	13	1.1	16	8	2.0	3.5	1.8	1.5	87
12/14	6.2	6.0	1.0	5.2	5.0	1.0	6.4	2.4	2.7	65
12/18	3.6	2.8	1.3	5.7	3.5	1.6	4.2	2.7	1.6	98

[1] D.F. = $\frac{\text{Gross}}{\text{Centrifuged}}$.

[2] D.F. = $\frac{156}{\text{Col. 9}}$.

in series to two additional ponds. Effluent from the third pond was diluted with the Imhoff tank effluent and the combined wastes then passed through a Dunbar bed. The effluent from the final treatment system never registered a count above background.

Samples of sludge from the bottom and walls of the ponds contained relatively great amounts of radioactive material. Table XII reveals that some of the samples from Pond No. 1 showed as much as 600,000 counts per minute per gram (c./m./g.) The relative count as taken with a G. M. tube was probably higher, since there was ample opportunity for self-absorption in the dried material. Apparently most of the radioactive substances remained in the sludge until masses broke free and rose to the surface. The floating scum occurred only in Pond No. 1 and contained considerable amounts of radioactive isotopes. Upon microscopic examination the scum was found to contain a multitude of different algae. The predominant forms were *Ankistrodesmus, Scenedesmus armatus, Navicula,* and a number of diatoms.

Tests on the radioactivity in the effluent of Pond No. 3 were continued for six months to determine if the radioactivity was being gradually released into solution or if it was being released as rapidly as it had been deposited. Apparently it was released at a gradual rate, for the effluent remained at about 3 c./m./ml. above background until the ponds were cleaned. At the time of cleaning (June 8, 1954) the bottom sediment in Pond No. 1 contained 60 c./m./g.

TABLE XII.—Radioactivity in Bottom Sediments

Date	Radioactivity per Grain of Dried Sludge (c./m.)			Remarks
	Pool 1	Pool 2	Pool 3	
Jan. 8	600,000	—	—	Bottom
25	22,000	10,000	370	Bottom
25	81,000	30,000	1,800	Side
29	125,000	—	—	Floating scum
Feb. 2	38,000	72,000	1,800	Bottom
4	35,000	8,000	2,000	Bottom
11	16,000	8,000	7,000	Bottom
12	10,000	4,000	5,000	Bottom
12	135,000	—	—	Floating scum
18	11,000	11,000	2,000	Bottom
18	110,000	—	—	Floating scum
June 8	60	40	15	Bottom

of dried sludge as compared to 600,000 c./m./g. recorded on January 8, 1954. The bottom sediment in Ponds No. 2 and 3 on June 8 contained about 40 and 15 c./m./g. of dried sludge, respectively. Unfortunately, the amount of sludge could not be recorded with accuracy; but it is estimated that approximately 20, 15, and 10 gal. of algal debris having a dried weight of about 30 g. per gallon was present in the Nos. 1, 2, and 3 oxidation ponds, respectively. Although oxidation ponds usually have relatively small amounts of bottom sediments, these tests have indicated that it will be necessary to incorporate into oxidation pond design some means for periodically removing the contaminated sediments.

Sr^{89} Uptake

Sr^{89} (Isotopes Division Catalog No. 38-FA) has a half-life of 53 days and contains less than 10 per cent of Sr^{90}, which has a radioactive daughter, Y^{90}. Radioactive strontium is one of the more abundant elements in mixed-fission products and is an element which upon ingestion is readily incorporated into the body, particularly into the bone structure. Therefore, the radioactive isotopes of strontium must be separated from a waste solution if any disposal program containing mixed-fission products is to be successful.

Batch-type experiments were conducted using Erlenmeyer flasks containing settled sewage, oxidation pond effluent, synthetic substrate, and either tap or distilled water. Some of the solutions received varying numbers of algae; others received only enough waste to insure proper seeding. A summary of the data (Table XIII) indicates that bacteria and sewage organisms are as effective in removing strontium as algae. In the presence of a citrate the removal of strontium by algae dropped from about 22 to 2 per cent, whereas the removal remained the same where only bacteria were present. Slight fluctuations in pH and populations in algae did not appear to cause significant changes in uptake. As a matter of fact, algae suspended in distilled water for a day removed as much strontium as algae grown in a nutrient-substrate for a somewhat longer period of time. Accumulation of strontium ions at times appeared to follow a straightforward ion exchange process. Tests No. 6 and 8 (Table XIII) show the effect of increased food and an increasing population on the uptake of Sr^{89}. The reduction of strontium ion uptake by algae in presence of a complexing agent indicates that the complexing agent must first be attacked by bacteria if stronium is to be removed. Although only 20 per cent of the radioactive strontium is picked up by algae and bacteria in batch-type experiments, it is significant. If the foregoing relationship holds for a single pass and assuming that a new population of algae is available every five days on the average, about 70 per cent of the strontium might be removed during a 20-day detention period, providing either bottom sediments or suspended algae were periodically removed.

Additional experiments of the continuous-feed type using both flasks and 12-gal. aquaria showed that, with the batch type experiments, virtually the same range of uptake was attained —with one exception. In the batch experiments a complexing agent such as citrate materially reduced the uptake, whereas in the aquaria the uptake was increased. This exception might be explained in that a strontium-citrate complex existed in the batch experiments, and since citrate is not readily available as food to most algae, insufficient time was allowed for bacterial action to break the complex. However, in the aquaria sufficient time was available. Consequently, the bacterial and algal population increased in the aquaria as a result of the increased organic ma-

TABLE XIII.—Summary of Data on Sr^{89} Removal by Algae, Bacteria and Other Suspensions

Test No.	Influent	pH		Max. Algae Pop. 1,000/ml.	Removal (%)	
		Av.	Range		Av.[1]	Range[2]
1	Sewage	7.1	6.5–7.7	0	18	14–24
2	Oxidation pond effluent	9.4	8.4–10	400	22	11–33
3	Tap water and algae	8.5	8.0–9.3	2	23	17–29
4	Aquaria effl. (syn. sewage)	9.4	8.5–10.4	1,300	27	19–47
5	Test 1 + 1,000 p.p.m. citrate	7.8	7.0–8.5	0	17	11–21
6	Test 2 + 1,000 p.p.m. citrate	9.8	8.9–10.5	805	2	0–7
7	Test 3 + 1,000 p.p.m. citrate	8.2	7.7–9.1	2	1	0–7
8	Test 4 + 1,000 p.p.m. citrate	9.8	9.2–10.2	1,000	18	12–22
9	Distilled water + algae	8.3	8.0–8.7	2	21	15–24
10	Distilled water + 2,000 p.p.m. urea + sewage organisms	7.6	6.5–8.0	0	14	7–19
11	Test 10 + algae	7.5	7.3–8.0	2	18	12–31

[1] Radioactivity removal based on average under equilibrium conditions near end of run.
[2] Radioactivity removal based on 15 days of tests.

terial, which in turn increased Sr^{89} uptake from 10 per cent in each of three series-connected aquaria to a maximum of 35 per cent and an over-all removal of 80 per cent. The detention period was 20 days and daily additions of Sr^{89} were made to the first aquarium.

The effect of magnesium ion on strontium uptake has been observed by Morgan (4) to be considerable, but in the heterogeneous conditions which exist in algae ponds the effect was not readily detected.

Ce^{141} Uptake

Another radioisotope that may be obtained in large quantities from reactor operations is Ce^{144}, a pure beta emitter with a half-life of 290 days. Its daughter, Pr^{144}, although of relatively short half-life (17.5 min.), gives off 3.0 Mev beta particles and 0.2 to 1.2 Mev gamma radiation, which make both mother and daughter undesirable as water contaminants. For practical purposes, however, mainly Ce^{141} (Isotopes Division Catalog No. 58–FA) was used in the experimental work: its chemical behavior is the same as Ce^{144}, although the potential health hazard involved in its use is much less, thereby requiring less manipulative time and effort and less cost.

Jar cultures containing 500 ml. of algal suspensions in selected concentrations were inoculated with Ce^{141} to provide an initial beta-gamma concentration of about 3,000 c./m./ml. The initial algal concentrations were 3.8×10^5 cells per ml. (designated as 100 per cent), 1.9×10^5 cells per ml. (50 per cent), 9.6×10^4 cells per ml. (25 per cent), and a distilled water control (0 per cent) containing 2 p.p.m. $HgCl_2$. Each of these cultures was adjusted to an initial pH of 10 with NaOH. At the end of 1 hr., 1 day, 3, 5, 7, 9, 11, 13, 15 and 17 days, respectively, a thoroughly mixed representative sample was withdrawn from each culture and observed for (a) pH; (b) radioactivity, beta-gamma concentration in c./m./ml. on both gross portions and centrifuged supernatant; (c) algae concentration, 10^6 cells per ml., as determined by microscopic count in a Levy-Hauser hemacytometer counting chamber; and (d) predominant genus of algae present in the culture.

Concurrently with this experiment similar jar tests were made starting with all conditions the same except for the initial pH values, which were

adjusted by NaOH or HCl to 2, 8, and 11. A distilled-water control with 2 p.p.m. $HgCl_2$ was carried at each initial pH value. The mercuric chloride served to prevent any development of algae in the controls since no attempt was being made to perform pure culture work or to use aseptic techniques, and since past experience had indicated that algae can obtain CO_2 and NH_3 from the atmosphere to establish at least a limited growth even in distilled water. The observation schedule for this experiment was 1 hr., 1 day and 3 days, etc.,—terminating after the 15th day. All cultures in both experiments were thoroughly stirred three times daily.

Experimental data as plotted in Figures 2 and 3 may be summarized as follows:

1. Algae are capable of removing as much as 95 per cent (equivalent to a D. F. of 20) of the radioactivity contained in an inoculum of Ce^{141}.
2. The mechanism of removal is likely to be very erratic and may vary in efficacy with fluctuations in such controlling factors as light, temperature, pH, nature and concentration of nutrients, and rate of growth.
3. Some of the Ce^{141} was adsorbed by the glass beaker. The weight concentration was of the order of 1×10^{-12}, and occlusion of an appreciable proportion of the Ce^{141} ions by the glass itself was evident.

Discussion

Study of algae by other investigators indicates selectivity on the part of certain types with regard to particular elements. This would indicate that different species would show differing efficiencies in taking up radioactive isotopes. Although a wide variety of algae were encountered in the studies here reported, they seem to have had no practical effect upon uptake.

The mechanism of the uptake of radioactivity by algae and bacteria in oxidation ponds can be placed in two categories. In one category is P^{32}, which enters into cell phosphorylation processes in relatively large amounts. In this case the radioactive phosphorus ion is in competition with the stable phosphorus ion and the uptake, consequently, is dependent upon the ratio of the stable to the radioactive phosphorus ions. The extent to which the phosphorus will be used will also be related to the nutrient available. Algae and bacteria may temporarily remove virtually all of the P^{32} from sewage or laboratory waste, especially when the concentration of phosphorus is limiting or below the other necessary growth-promoting elements.

Strontium is in the second category in the method of uptake of radioactivity. Action of the various isotopes is dependent upon diverse chemical and physical phenomena which must take place before separation and uptake are possible. Strontium and similar radioactive isotopes may be in competition with their stable counterparts and may also be in competition with elements which are similar in ionic size and chemical behavior. These elements may actually be accepted by the cell as a replacement or a required ion. The removal of Sr^{89} by algae and bacteria may be great, depending mainly upon the state of microscopic plant growth.

Other isotopes, such as I^{131}, may also be listed under the second category, although these apparently do not become a part of the algae or bacteria cell structure. The I^{131}, and possibly other mixed fission products, may combine with trace elements to form insoluble compounds as a result of the chemical and biochemical changes created by the complex biological community existing in oxidation ponds. The fact that considerable amounts of the long-lived mixed-fission products actually become involved in bottom sediments illustrates the tremendous amount of biological and chemical activity present in an oxidation pond.

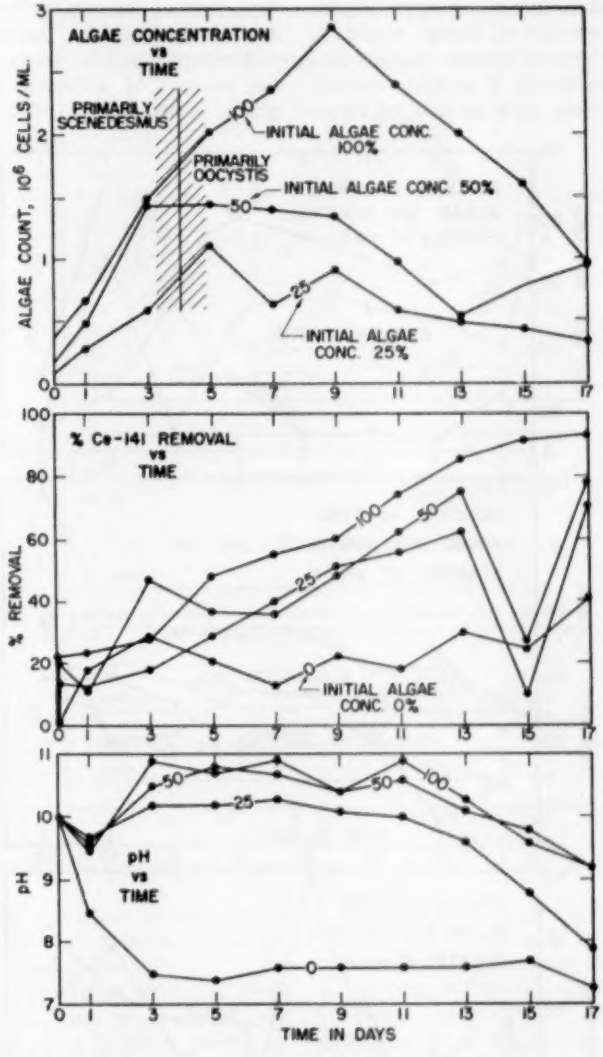

FIGURE 2.—Effects of various initial algae concentrations on removal of Ce^{141}.

Continuous applications of mixed-fission products having relatively long half-lives could conceivably create several local problems. As an example, disturbance of the "hot" benthic sludges might redistribute the concentrated radioactivity into solution. A proportionate amount of this radioactivity coming from the bottom might then cause somewhat of a shock load to a diluting body of water.

Considerable amounts of radioactivity in bottom sediments may dictate the use of concrete-lined oxidation ponds constructed so that the sludges can be scraped together. The collected sludge could be given additional concentration treatment or stored in

special radioactive-decay type digesters. The volume of sludge would be small and special storage tanks could be used, especially if another concentration process, such as vacuum filtration, proved inadequate because of the semi-liquid state of the aged sludge.

Another possible means of reducing the amount of sediment in oxidation ponds is some form of filtration and

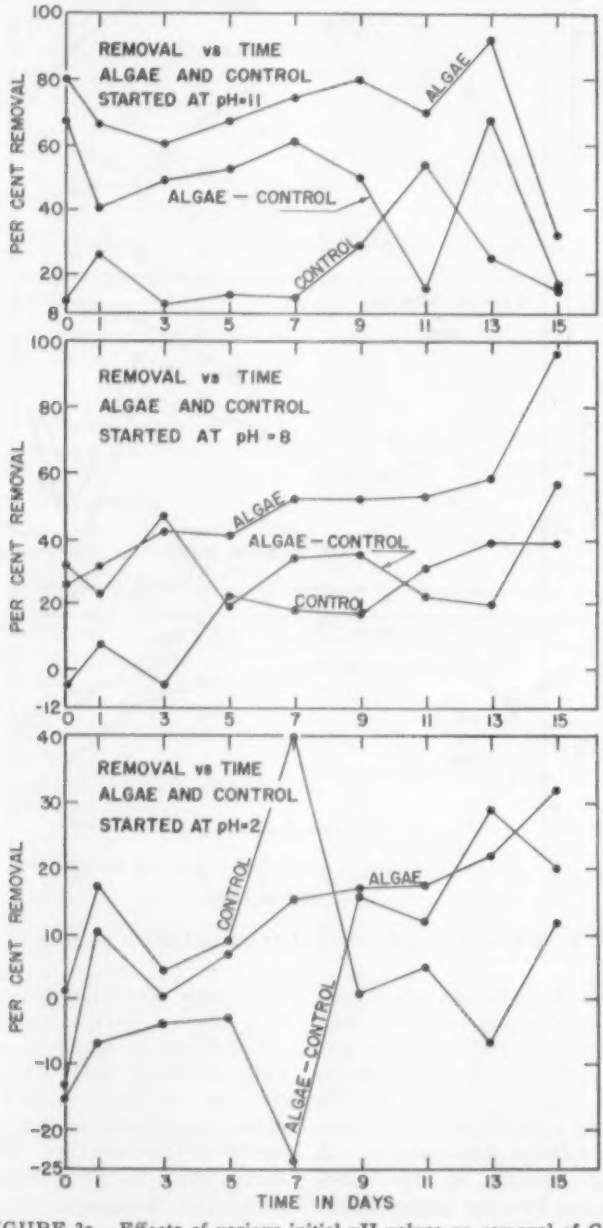

FIGURE 3a.—Effects of various initial pH values on removal of Ce^{141}.

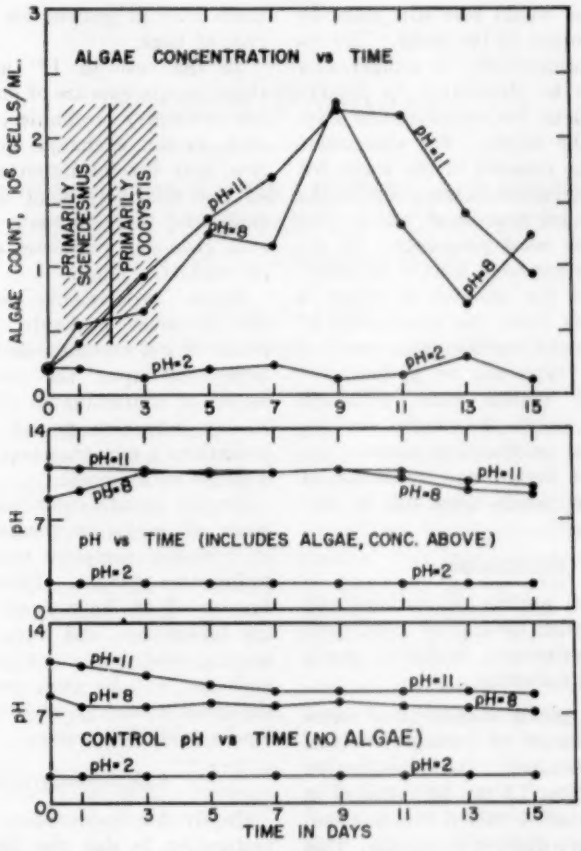

FIGURE 3b.—Effects of various initial pH values on removal of Ce^{141}.

recirculation. Such a scheme would have the benefit of maintaining a dynamic biological population.

Whether algae in an oxidation pond can be maintained at the optimum growth stage is a problem to be investigated, for algae and bacteria are most effective in stabilizing organic wastes and concentrating trace elements when they are in the logarithmic growth phase. Another interesting possibility for maintaining the desired state of algae growth is to use ultrafine screens and periodically remove a portion of the algae. This partial removal of algae will leave some as seed to continue reproduction, which will result in further uptake of radioactivity.

Consideration of oxidation ponds indicates that using them to grow crops of radioactive-contaminated algae, later to be removed from the effluent, will present some problems. Many of the oxidation pond installations in Texas produce effluents which are low in turbidity, at least at times, although algae growth may have been luxuriant earlier in the series of ponds.

This suggests that if the total detention period is long enough the algae and bacteria will die and many will become incorporated in the bottom sludge where, if half-lives of radioactive isotopes are short, much of the radioactivity will disappear. The supernatant liquid which would become effluent would retain some radio-

activity, but would lose still more by actual detention in the pond. The remaining radioactivity, if dangerously high, might be eliminated by returning the effluent for recirculation after removing the algae. An alternative would be the removal of the waste for algae concentration at the point in the oxidation pond process at which they are blooming most profusely. If the waste which has been filtered or otherwise treated for removal of algae is still unstable from the standpoint of oxygen demand, further treatment of appropriate type can be given.

It would appear that, although algae promise to be useful in the treatment of radioactive wastes, the technique of design and operation of the oxidation ponds must still be further developed.

Conclusions

Studies of uptake of radioactivity by algae under laboratory conditions and in experimental oxidation ponds indicate the following:

Oxidation ponds should be of value in the treatment of certain low-level radioactive wastes. Decontamination factors of about 1.3 can be obtained in the case of aged mixed-fission products for each 5 days of detention. This relatively low detention factor can undoubtedly be increased by periodically removing a portion of the algae population.

Algae-bacteria populations are more desirable for concentration of P^{32} than are bacteria populations, since the activity is detained in the larger algal cell for a longer time. The algae populations can be maintained at an optimum level of growth for a longer period of time.

In the case of I^{131} and of Cs^{137}, algae populations are of no importance; but secondary mechanisms of removal, such as ion exchange and precipitation, may become important by virtue of the relatively long detention periods and the multitude of biological and chemical reactions occurring in an oxidation pond.

Batch experiments indicate that Sr^{89} removal probably occurs as a result of ion exchange and is partially dependent upon the continuous removal of contaminated cells. With a 20-day detention period under ideal conditions a decontamination factor of 3 might be obtained.

Proper growth conditions and operation of oxidation ponds will result in virtually complete removal of the radioactive cerium. Decontamination factors of 20 have been obtained in the laboratory, and under actual operating conditions the opportunity for occlusion will be even greater due to the greater variety of suspended matter in oxidation ponds.

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Stream Pollution

AIR POLLUTION CORRECTIVE MEASURES COMPLICATING WATER POLLUTION CONTROL PROBLEMS *

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Air pollution control and water pollution control fundamentally have a common purpose—preservation of natural resources. In view of this, both fields are directly related to each other. This may not be evident, considering the nature of the pollutants dealt with, the differences in the control equipment and procedures, the differences in the various fields comprising each general subject, and the organization of separate control bodies both by industry and government. Despite these apparent differences there is a direct relationship between air pollution control and water pollution control.

This relationship is no doubt quite apparent to those who are engaged in activities concerning the control of both air and water pollution. Unfortunately, however, there are individuals who do not appreciate the existence of such a relationship and, of course, the consequences which might arise. Evidence that the relationship between air and water pollution control is not fully appreciated lies in the fact that, of the many papers dealing with wet methods for air pollution control which have been reviewed, only about 5 per cent made any reference to the effect of the procedure described on water pollution control.

It is not only natural but also required by management in many instances that waste disposal problems be handled in the most economical manner. Although this policy is recommended, it can, unless management is fully advised as to the relationship, confine the designer within narrow limits. As a result of the relationship between air and water pollution control, sufficient latitude must be permitted so that both the primary problem and any secondary problems created can be effectively and economically solved at the same time.

Secondary Problems

For instance, an emission to the atmosphere might be controlled merely by installation of a scrubbing procedure. The air pollution problem has been solved, and one might stop at this point with the feeling that the project had been properly handled. This is an erroneous conclusion, as a liquid effluent has been created whose treatment should be considered before the problem can be said to be solved.

What effect does this effluent have on the existing water pollution control program? Can this waste discharge be combined with others and treated in the present facilities or

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does it require special handling? These questions are representative of the many that will develop and must be answered if the problem is to be properly handled. This simple example will point up the existence of the definite relationship of air to water pollution control. It is emphasized, therefore, that consideration given a particular problem be broad enough to include all aspects of the pollution control program. An air pollution problem must not be solved at the expense of water pollution control. The opposite, of course, is also true. This is a philosophy that is recommended for adoption by all persons engaged in air and water pollution control activity, including governmental personnel.

Directionally, the relationship exists in greater proportion from air to water than from water to air, although water pollution control can contribute to air pollution. For example, odor-bearing liquid wastes in themselves are sources of air pollution, while treatment of certain liquid wastes can cause air pollution.

Air Pollutants

Air pollution control involves two principal types of pollutants—particulate matter and gaseous substances. Dusts and mists are classed as particulate matter. Vapors are included in the gaseous substance category.

Emissions of particulate matter to the atmosphere can be controlled by gravity settling, inertial separators, packed beds, cloth collectors, electrical precipitators, sonic waves, air filters, and scrubbers. Interest herein lies in scrubbing, as this is the principal procedure of the foregoing list which has an effect on water pollution. The other procedures listed are so-called dry procedures, as the pollutant is recovered in the dry state without production of a liquid effluent.

Gas and vapor abatement employs the following procedures: dispersal through stacks, incineration, catalytic combustion, adsorption on solids such as carbon, absorption, and scrubbing. Absorption and scrubbing are the methods having present interest as these produce liquid effluents which can complicate the water pollution control program.

The character of the liquid effluent produced by a so-called wet air pollution control procedure depends on the nature of the pollutant and the composition of the scrubbing agent. The pollutant that might be encountered in the liquid effluent can be a solid such as dust from ore processing and other operations in the mineral industry or from gas cleaning. In most cases of solids removal by scrubbing, water with or without a wetting agent is used.

The pollutant picked up by the scrubbing liquid can also be a gas or vapor such as hydrogen chloride, sulfur oxides, ammonia, and others. Since water is the universal solvent, it is the most common of the scrubbing agents, although certain chemical solutions are employed because their affinity for a particular gaseous pollutant may be greater than that of water. On occasion a particular chemical scrubbing agent may be used because it can react with the pollutant to form a solution that can be sold.

Treatment Requirements

The nature of the effluent from the scrubbing operation will dictate the type and degree of treatment that might be required so that the assimilative capacity of the receiving stream or effluent standards, if any, will not be exceeded. In this connection a study should be made to determine whether the new waste discharge can be handled by the existing treatment facilities and what effect its inclusion will have on the characteristics of the total waste effluent leaving the plant. Such a study should consider co-treatment; that is, treatment of one

waste with another. Combination of the new waste discharge with total waste effluent without exceeding legal limits might be possible in some instances. As this infers dilution, it should not be adopted until a careful study has been made of the water pollution control law in effect so that violation will be avoided.

Several treatment methods are applicable to a scrubbing effluent containing suspended solids. These are plain sedimentation, plain sedimentation plus chemical coagulation, filtration through sand or other media or by vacuum precoat means, and air flotation with or without chemical coagulation. Sedimentation with or without chemical coagulation produces a sludge which must be handled. Filtration also creates a secondary problem. In some cases the filtering medium is removed from the unit and discarded or it may be washed and returned to the filter; in other kinds of units the medium is washed in place. Vacuum precoat filtration produces a filter cake, whereas air flotation gives a froth, both of which require disposal.

Disposal of End Products

Final disposal of the end products (sludge, filter wash water, filter cake, and froth) is both difficult and costly. Lagooning and piling on land have been used extensively. In many cases such practices are not possible because the required land is not available.

Application of incineration requires dewatering of the solids so as to decrease the amount of heat needed. Because the solids generally are not completely combustible, incineration becomes a drying procedure to produce a material that can be used as fill, dumped on land, or, in a few fortuitous instances, sold. Liquid cyclones and centrifuges may find application in removing solids from scrubbing agents. Disposal of the solid residue from these devices requires consideration.

Gases, vapors and particulate matter that are soluble in the scrubbing agent create an effluent that requires consideration of treatment procedures (such as sedimentation and filtration) beyond those classed as mechanical. The effluent must be studied to ascertain its character (such as its acidity or alkalinity, its oxygen demand, and other factors). Having determined the character of the effluent it is necessary to determine whether it can be handled properly by the existing treatment facilities and what effect its admission into the system will have on the streams that are currently being handled satisfactorily.

The various treatment methods involving neutralization, oxidation, and other chemical reactions applicable to effluents from scrubbing operations are well known. In view of this their detailed consideration herein is not warranted. Each case, however, should be given careful consideration, particularly as to the effect of the created waste stream on the present treatment facilities and how it can be assimilated into the existing system.

Liquid Effluent Volume

The effect on water pollution control by a wet air pollution control installation can in some cases be minimized by recirculation of the scrubbing agent as compared to once-through use. Recirculation is applicable to situations involving removal of particulate matter and, of course, is a fundamental feature of the regenerative procedure.

Complication of water pollution control can be avoided by use of a wet regenerative procedure. In this type of operation the scrubbing agent bearing the contaminant is regenerated and recirculated. The contaminant removed by regeneration requires final disposal. In some cases the substance might be disposed of by burning, whereas in others it might be sold or used in the plant where it is produced.

Although primarily a process operation, a regenerative procedure that is used extensively by the oil industry has air pollution significance. This is a sweetening operation used to remove hydrogen sulfide from gas. The scrubbing agent or absorbent employed is an amine, phenolate, or phosphate solution. The hydrogen sulfide is absorbed by the chemical agent, which is regenerated by heating. This drives off the hydrogen sulfide, which is collected and the regenerated absorbent is recycled. The recovered hydrogen sulfide has been sold in some cases, but has also found favor as a raw material for production of sulfur by the modified Claus process. In some cases the hydrogen sulfide is burned. Due to the toxicity of hydrogen sulfide, any burning operation requires careful control and supervision.

Legal Control of Air Pollution

Employment of combustion as a means for disposal of waste gases should consider the nature and amount of the combustion products so as to avoid a nuisance and violation of any legal control on air pollution.

Caustic washing of petroleum fractions also is employed by refineries as a sweetening operation. The spent caustic contains mixed sulfur compounds and phenolic-type materials classed as acid oils. The spent caustic in itself is a source of air pollution, due primarily to its offensive odor. It also has considerable oxygen demand. Consequently its disposal is a problem.

A procedure which has gained acceptance involves neutralization and deodorization. In this method of handling, the spent caustic is admitted to a tower in which it flows countercurrent to a stream of flue gas. The neutralizing effect of the carbon dioxide in the flue gas springs the sulfur compounds, which are stripped by steam and burned in a special burner. The neutralizing action also releases the acid oils, which are recovered from the liquid effluent from the contact tower in a settling drum. The final effluent, although alkaline, is deodorized and can usually be combined in the total waste water effluent without substantial effect on its character. This procedure permits disposal of a particularly troublesome waste without complicating the water pollution problem, and at the same time considers air pollution. Acid can be used in place of flue gas for neutralization.

Selection of Treatment Procedure

It was indicated previously that consideration of a particular problem should be sufficiently broad to include various control procedures so that selection can be made on the basis of economics, performance, and effect on water pollution control. The following example will serve to illustrate this point.

Assume that solids must be removed from a gas stream. A study of control procedures is made, including water scrubbing and dry methods involving electrostatic precipitation, cyclones, and multiclones. The results of this study are given in Table I.

Based on performance, Table I indicates that water scrubbing is the most attractive. This view is also true from the cost standpoint. However, scrubbing produces a liquid effluent

TABLE I.—Comparison of Procedures for Minimizing Emissions of Particulate Matter to the Atmosphere

Procedure	Cost (% of highest)	Efficiency (%)	Solids Removed (% of total)
Water scrubber	81	99+	100+
Water scrubber plus effluent treating facilities	95	99+	100
Electric precipitation	100	95	95
Cyclones	61	60	60
Multiclones	46	60	60

which can complicate water pollution abatement and must be considered. The facilities required for the treatment of the effluent in this instance increases the investment. Consequently, the procedure loses its economic attractiveness.

In some cases it will be found that the existing waste-water treatment facilities can accept the liquid waste effluent produced by the air pollution control installation. This avoids the provision of new waste disposal facilities. However, in this situation the cost of the air pollution control installation should include a portion of the cost of the existing treatment facilities in relation to the load contributed by the new effluent. In this situation such cost would be added to the cost of water scrubbing shown in Table I.

The point here is that all aspects of cost should be fully considered, inasmuch as selection of what appears to be the least expensive is quite often a mistake. Each procedure should bear its full share of associated costs which must be considered in making the final decision. This, of course, involves compromises influenced by local factors, such as legal limits, that must be met.

Conclusion

Experience indicates that the relationship between air pollution control and water pollution control is either ignored or is not appreciated. Nevertheless, the relationship is real and can have a substantial influence. It is essential that the influence of air pollution control on water pollution control be carefully considered by both the designer and the control official.

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USEFUL VARIATION ON CHURCHILL'S METHOD OF STREAM CAPACITY ANALYSIS

By George A. Rhame

Engineer, South Carolina Water Pollution Control Authority, Columbia, S. C.

Churchill's logical straightforward approach to analysis of a stream's capacity to assimilate pollution (1) is a great advance in methods of studying such problems. Nevertheless, one attempt to apply it to a problem of some importance immediately ran into a considerable difficulty.

The stream in question emerges from the bottom of a large reservoir with relatively low B.O.D. and low dissolved oxygen. The dissolved oxygen content begins to rise immediately and continues to do so after passing the first source of significant pollution. Farther downstream is a large source of B.O.D. load which causes a severe depletion of dissolved oxygen that an estimate of B.O.D. removal is required. Finding a basis for "D.O. drop" presented a problem.

Some thought developed the idea that there should be a systematic relation between the percentage saturation of D.O. and the B.O.D. in a stream at any point in its flow. Such a relation would lump together all of the factors covered by Churchill without the necessity of a reference point for "D.O. drop." From this relation a calculation of treatment requirements could be made using principles set forth by Churchill.

To test the correctness of these assumptions, Churchill's data were treated by this method. Station F was taken as the basis of computation because it showed the lowest dissolved oxygen.

The "D.O. correction" for improvements in bottom conditions was not used in these calculations. Phelps (2) and others have shown that satisfaction of the oxygen demand of these deposits may take many years. In the opinion of the writer, inclusion of Churchill's "D.O. correction" factor in calculations aimed at determining pollution reduction requirements in a critical situation might lead to some years of acute disappointment and controversy.

All of Churchill's D.O. and temperature data for Station F were converted to percentage of saturation, then tabulated and plotted against the corresponding B.O.D. After some amateur floundering, it was found that a semilogarithmic curve best fitted the data and the equation was derived.

Because of the peculiar distribution of points on the plot it was thought that perhaps the equation constants were different at various water levels. Accordingly, the data were divided at median flow and each half was plotted separately. Curves and equations are shown in Table I and Figure 1.

Suppose, now, that it is desired to estimate the degree of B.O.D. removal required at Industrial Plant so as to have a minimum of 2.5 p.p.m. D.O. at 23° C. at 280 c.f.s. flow at Station F.

At 23° C., 2.5 p.p.m. D.O. would represent 28.8 per cent saturation. From the center curve, 28.8 per cent saturation would be maintained with 5.0 p.p.m. B.O.D., which would equal 7,560 lb. of B.O.D. per day at 280 c.f.s. Since the natural B.O.D. at 1 p.p.m. would be 1,510 lb., the indus-

TABLE I.—Equations for Curves of Figure 1

Water Level	Equation	B.O.D., x (p.p.m.)	% Sat., y
Above median	$\log y = 1.9889 - 0.09038X$	0	97.5
		22	9
All flows	$\log y = 1.0228 - 0.09178X$	0	83.7
		21	0
Below median	$\log y = 1.7670 - 0.07795X$	0	58.5
		22.6	0

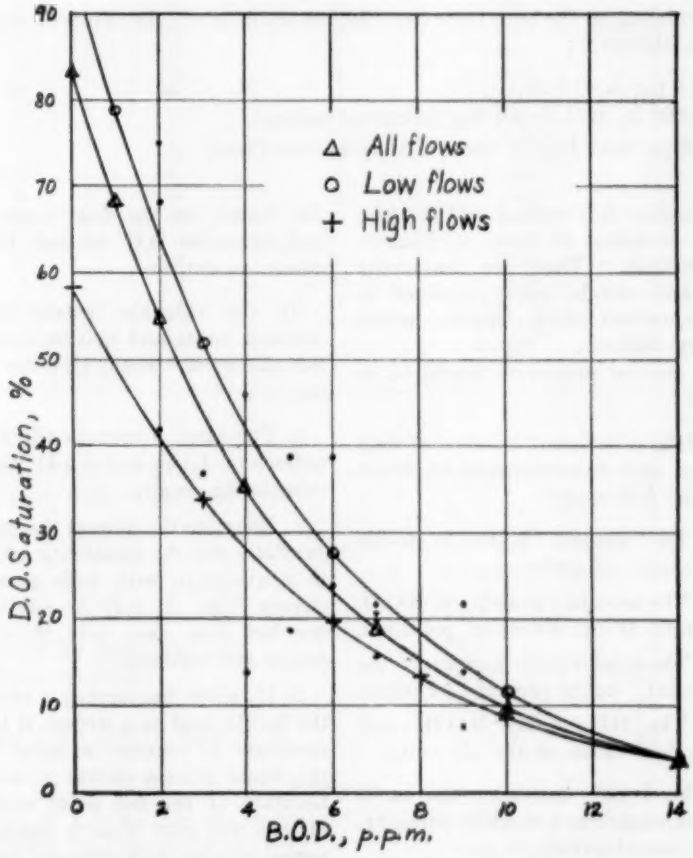

FIGURE 1.—Relationship of D.O. saturation to B.O.D. at Churchill's Station F.

trial residual at Station F would have to be 6,050 lb. after B.O.D. removal at the source.

Comparison of load added at Industrial Plant with present load at Station F minus natural load (Churchill's Table II) shows that the river absorbs about 61 per cent of the added load between the source and Station F. Then:

Required industrial residual at Station F = (1 − 0.61) × (Load at Ind. Plant after treatment).

$$\text{Industrial Plant after treatment} = \frac{\text{Required residual}}{0.39} = \frac{6{,}050}{0.39}$$

= 15,510 lb. per day.

Removal at Industrial Plant = 35,600 − 15,510 = 20,090 lb. per day

$$= \frac{20{,}090}{35{,}600} = 56 \text{ per cent.}$$

Also, 50 per cent removal at Industrial Plant gives 2.2 p.p.m. D.O. at Station F.

Calculating on the same basis from the low-water curve, the following conditions hold at Station F:

1. 3.9 p.p.m. B.O.D.
2. 5,900 lb. B.O.D. per day industrial residual.
3. 58 per cent B.O.D. removal at Industrial Plant.

Obviously, this method will not give results identical to those of Churchill's method. They are reasonably close, and can be easily obtained in some situations which otherwise would be very difficult.

The general procedure would be as follows:

1. Make a sufficient number of field analyses and measurements to determine the following:

(a) The "natural" B.O.D. of stream above source of pollution.

(b) The amount (pounds) of B.O.D. discharged at the source of pollution.

(c) The approximate location of the "sag point" under present conditions.

(d) The D.O., 5-day B.O.D., and stream flow values at the sag point.

2. Plot 1 (d), determine the curve and the equation (probably straight-line or semi-logarithmic type).

3. Estimate the critical condition in the stream for the flow, temperature, and minimum D.O. desired, then calculate as outlined.

To the valuable instructions and cautions contained in Churchill's paper the writer would add the following:

1. The more numerous the determinations of 1 (b) and 1 (d), the more reliable the results.

2. Examine the data at the sag point carefully for the possibility of change in relationship with wide changes in stream flow. It may be advisable to use low flow data only if sufficient points are available.

3. If, after instituting a change in the B.O.D. load on a stream, it becomes necessary to consider another change, the whole process should be repeated. Location of the sag point and other factors will vary after a considerable period of time with changed load conditions.

APPENDIX

Calculation of Curve for Station F by Least Square Method (3)

B.O.D. X	X^2	% Sat. y	log y	X log y
3	9	37	1.5682	4.7046
6	36	39	1.5911	9.5466
7	49	21	1.3222	9.2554
2	4	75	1.8751	3.7502
5	25	39	1.5911	7.9555
7	49	22	1.3424	9.3968
7	49	20	1.3010	9.1070
7	49	16	1.2041	8.4287
9	81	14	1.1461	10.3149
7	49	16	1.2041	8.4287
4	16	46	1.6628	6.6512
10	100	11	1.0414	10.4140
9	81	8	0.9031	8.1279
7	49	13	1.1139	7.7973
7	49	14	1.1461	8.0227
9	81	22	1.3424	12.0816
6	36	24	1.3802	8.2812
4	16	14	1.1461	4.5844
17	Not used	0	—	—
2	4	42	1.6232	3.2464
2	4	68	1.8325	3.6650
2	4	75	1.8751	3.7502
Σ 122	840	—	29.1822	157.5087
Av. X = 5.81	N = 21			

Calculations

$$\begin{cases} 21a + 122b = 29.1822 \\ 122a + 840b = 157.5087 \end{cases}$$

$$\begin{cases} 122a + 708.82b = 169.5486 \\ 122a + 840.00b = 157.5087 \end{cases}$$

$$131.18b = -12.03.99$$

$$b = -0.09178$$

$$21a = 29.1822 + 11.1972$$

$$21a = 40.3794$$

$$a = 1.9228$$

$$\log y = 1.9228 - 0.09178\,X$$

y	x
83.7	0
67.8	1
54.9	2
35.9	4
19.1	7
10.1	10
4.3	14
0	21

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THE OPERATOR'S CORNER

CONDUCTED BY DONALD P. SCHIESSWOHL

WHAT'S IN A NAME?

When sewage treatment plant operators gather together in informal discussion, the subject all too frequently turns to the names by which their plants are known and the labels applied to the men who operate these facilities. The conversation revolves around the stigma that is attached to the men and their families who share in this key job of safeguarding the health of their communities. Its the effect on their families that causes these men the most concern.

Efforts have been made in the past to do something about the name sewage treatment plant operator. Several Member Associations have conducted surveys to obtain suggestions. All apparently with little success. More recently the California Sewage and Industrial Wastes Association has proposed a contest to solicit a new association name for the consideration of its membership. A name that will "get away" from the word sewage.

Alas, that a rose by any other name would smell as sweet. One operator recently suggested a change in the operator's label to something like "Sanitation Technician" that would differentiate between a regular run-of-the-mill labor hand operating a plant and a person licensed in a technical field.

But is the mere changing of a name the thing that will change the public's concept of their treatment facilities and the men who operate them? A sanitation technician or engineer might be a street sweeper—and if he operates in a slovenly, poorly publicized manner he will always be a street sweeper.

Everyday the public is bombarded with words and ideas to create word associations that will have a certain desired effect. Familiar are the word associations that have been built up by manufacturers in order to attach some desired characteristic to their product.

When the word "sewage" comes up in a discussion among a group of average citizens it starts a process of word associations. The chain of thought runs: sewage—smell—dirty—filthy—nauseating. It is not difficult for the mind to transfer this chain of thought to imply that anyone associating with sewage must be a pretty filthy, low-grade sort of individual.

It is fortunate that word associations and taboos can be changed and that the situation is not hopeless. Our progress in the field of medical science in connection with venereal diseases, cancer, and tuberculosis is attributed in a large measure to our freedom to approach the subjects with an open mind and to do away with old frustrating word associations.

So we in the sewage treatment field can take courage by continued diligence in treatment methods, good housekeeping and public relations. The latter is particularly important in helping to overcome the prevailing sentiment of the public. The solution to this vexing problem of unhappy word associations lies in making sewage treatment synonymous with cleanliness and health protection.

D. P. S.

PAINTING THE SEWAGE TREATMENT PLANT

By Charles Saunders

Superintendent, Linden-Roselle Sewage Treatment Plant, Linden, N. J.

Bright red valve handles, clean shining equipment surfaces, and light airy interiors make the once drab sewage treatment plant a pleasant place to work or to visit. An operator interested in his treatment facilities wants his plant to be a credit to the community and the finest around; efficient, attractive, economical and safe.

The proper paints are an important factor in achieving these desired qualities. The reason for this is that with the many distinctly different surfaces in a sewage plant, just one or two paints will not provide protection for equipment or attractiveness that will last. Different areas and types of service require special protective paints. For example, hydrogen sulfide fumes and other corrosive gases will soon attack the wrong type paint and damage equipment. Salt air presents an additional problem of corrosion protection at the Linden sewage treatment plant. Humidity is another factor, particularly in combination with certain sewage plant gases or gases from surrounding industrial plants producing corrosive conditions. Submerged areas and equipment also require special paints that won't become water-soaked and deteriorate, or fail as soon as they come in contact with greases, and chemicals.

Paint Selection

Attack from oils, chemicals, and greases in addition to fumes, high humidity, and varying atmospheric conditions are the major deteriorating influences to be watched in sewage plant painting. Careful plant design engineering calls for a thorough examination of the precise paint requirements to overcome these problems. This attention was given the design of the Linden sewage treatment plant, so that there have been no setbacks caused by shutdowns for repainting or equipment repair. The plant is attractive; easy to keep clean and a pleasure to operate.

In selecting the right paints for a sewage treatment plant, two types of economy should be kept in mind. Initial economy utilizing low-cost black bituminous paints, where these paints will do the job, and "long-lived" economy provided by special paints for color or corrosion resistant use. This long-lived protection reduces maintenance costs compared with costs resulting when an unsuitable paint is used.

Black bituminous paints were used on pipelines, grit collectors, settling tank interiors, and other surfaces that had to be protected against submersion in sewage and aggressive industrial wastes. Bituminous paints were also used to protect the exterior of pipes buried in ground saturated with saline and other corrosive liquids. Walls, ceilings, and floors of the buildings were painted with chlorinated natural rubber-base paints in color. An alkyd enamel, in color, was used on pumps, other equipment, and railings.

The use of the best paint for each service is not the entire story. No matter how good a paint may be, if it isn't applied to a thoroughly cleaned surface it just won't last. Any oil, grease, or other foreign substance on equipment surfaces prevents the paint from adhering to the surface it is to protect. Without a good bond the paint comes off when the underlying foreign material breaks down. This can be observed by examining the backs of pieces of peeled paint. Dirt, deteriorated paint, or oil discoloration will be seen. The extra effort put into surface preparation is well spent, adding many years of useful paint life. This extra life is also assured by care-

fully following the paint manufacturer's directions.

Operational Considerations

While protection of the taxpayers' investment in physical buildings and equipment is important, there are other equally good reasons for using good-quality paint. Reasons that also save tax dollars. A good-quality paint will retain its original color for years despite fumes, moisture, condensation, or exposure to the atmosphere. It will not be discolored by the oils and greases always present where machinery is involved.

Color Code

The color code used at the Linden sewage treatment plant is similar to that of the American Standards Association where physical hazards exist and equipment identification is necessary.

For the sake of attractiveness as well as utility, modifications were made in the A.S.A. code. In this way lines, valves, and equipment stand out clearly, but do not clash with the overall color scheme. The following modified color code was used:

Compressed air lines	Green
Overhead cranes and hoists	Yellow
Potable water lines	Blue
Valve handles, switch handles and moving parts	Red
Sewage discharge lines	Black
Sludge lines	Brown
Recirculation header	Brown with 6-in. red bands
Heating and steam lines	Blue with 6-in. red bands
Disconnect water supply lines	Black with 6-in. blue bands
Pumps, motors and shafts	Grey
Railings	Olive Green
Storage tank covers	Aluminum

Color Usage

As for room color schemes, the Linden plant uses a maroon floor enamel that brings a richness to the floors. This color combined with light grey walls and concrete grey ceilings produces a most pleasing appearance. The beauty of this color scheme has been commented on by many visitors, and the men find that it makes the surroundings pleasant to work in.

By using color in this way, it has been possible to bring out the best in building appearance. With paint alone the size and shape of an interior can be altered almost as drastically as if carpenters and masons had been called in. To give the effect of a "raised" ceiling, the wall color can be continued up onto the ceiling for a foot or so. To "remove" a piece of equipment that stands out too prominently against a wall, paint it the same color as the wall. If, for safety reasons, a piece of equipment must stand out, use the color that contrasts with the surrounding surfaces. Brighten darker areas with light colors, such as white or ivory that have a high light-reflecting value. This increases both the natural and artficial lighting, and makes the room cheerful and cleaner in appearance.

Safety

Good clean colors are not only desirable from an appearance standpoint, but they have a definite effect on efficiency and safety. It is an aid to efficient plant operation to have pipelines clearly discernable and unmistakably identified. A color code for pipelines and valves should be used. New employees should be schooled in the meaning of each color. This increases safety, particularly should an emergency occur. An occasion may arise suddenly when an employee is called on to assist in a

FIGURE 1.—The use of high gloss enamel paint in light colors makes an attractive easy to clean equipment room. Motors and tanks are grey, ceilings light grey, railings green and switch handles or moving parts red.

part of the plant where he is not ordinarily employed. He must know immediately, by color, what line is involved. The consequence for errors can be disastrous. One knows what would happen if the discharge of a positive displacement pump were closed while the pump was in operation.

The use of the color code helps make efficient operation almost a reflex action. Properly identified lines and valves give a three-dimensional flow diagram of the plant that enables personnel to comprehend the system.

Employee Morale

Attractive colors on piping, equipment, and the interior surfaces of the building have a decided effect on employee morale. Employees will respond more favorably to their duties in pleasant surroundings (Figure 1). A slovenly place to work produces slovenly work and reduces the desire to keep things neat and orderly. On the other hand, a plant with an easy-to-clean look will encourage personnel to keep it looking good.

As an aid to encouraging cleanliness, paint finish can be of great help. A

good paint will have a smooth, dirt-repellent surface that frequent cleaning will not pit even after years of service. A high gloss enamel will prevent dust, dirt, and oil from penetrating the finish. The smooth finish means far less cleaning and much faster cleaning when freshening up is in order.

Public Relations

An attractive plant does not stop with boosting employee morale and personal interest in plant efficiency; it has a significant effect on visitors. This is highly desirable because the majority of these visitors, although they are taxpayers, have never thought or wanted to think about what a sewage treatment plant looks like. Sad to say, they have a pretty uncomplimentary idea of what a sewage treatment plant looks like. Operators can take pride in their well-painted plant when visitors are surprised at the cleanliness and attractiveness which surrounds them. They will no longer think of a sewage treatment plant as a dumping ground, but as a scientifically operated service for the promotion of public health. The citizens also see in its efficiency the significant fact that communities served by a clean modern sewage treatment plant are much better and safer places in which to live.

Indirect benefit to the operating personnel accrues when city officials are favorably influenced on budgetary items by public opinion.

Obviously, the more visitors attracted to the sewage treatment plant, the more good-will ambassadors to herald its service to the community. Therefore, when the plant has been painted to look its best invitations to visit should be extended to civic organizations and high school science classes. High school students invariably are interested in the modern practical operations of their community service organizations.

So, look to the future. Examine your plant now to determine just how good paint can brighten it up, increase operating efficiencies, and lower maintenance costs. Then make plans to start a painting program or brighten a drab interior. You will be amazed at the results!

EXPERIENCES IN TREATING FERMENTATION PROCESS WASTES *

By H. W. Pitts

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Handling wastes from fermentation manufacturing processes puts a real load on that beast-of-burden of the organic waste disposal field, the high-rate trickling filter. The planning and designing of the biofiltration plant for treating the wastes waters at the Willow Island, W. Va. manufacturing plant of American Cyanamid Co., were presented in 1951 by Vogler, Griffin and Brown (1). It is recalled that, following the presentation of this paper, the remark was made that the operation of this plant would probably not be as simple as anticipated. The accuracy of this prediction has been affirmed during the past two years. Revisions have been necessary in the earlier concepts of loadings, strengths

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of wastes applied to filters, suitable filter media, and methods of multistage operation.

It should be noted that the operating experiences reported here are from a full-scale biofiltration plant that is an integral part of a manufacturing process. The flexibility and planned control of conditions, normally available in pilot plants, are sharply limited in a full-scale plant. Experimentation is the primary function of the pilot plant. In the full-scale plant uninterrupted treatment is the primary responsibility. Operating conditions are imposed upon the treatment plant by volumes and conditions of production. These conditions may vary considerably and at times may come and go without clear definition. For example, if the production department notifies the waste treatment plant that a bad batch of product must be sewered as soon as possible it is the responsibility of the waste treatment plant to take care of it. Sometimes this throws the treatment plant out of balance or causes unusual conditions to develop. It would be helpful at these times to do investigational work on these unusual conditions but, since continuous production does not permit time out for investigations, it cannot be undertaken. Some experimental work is carried out and some answers have been found, but many questions remain unanswered. The progress reported herein was made under such conditions.

Plant Description

The biological waste treatment plant at Willow Island was put into operation in 1952 to treat the wastes from the fermentation manufacturing processes. The principal products made by this department are crude pharmaceuticals and animal feed supplements.

The waste waters are principally the spent liquors from these fermentations. In addition, some of the floor washings, the laboratory wastes, and a small amount of sanitary sewage are sent to the treatment plant. The waste as it enters the plant has the following average characteristics: 5-day B.O.D. 4,500 p.p.m., pH 6.7, total solids 10,000 p.p.m., suspended solids 600 p.p.m., and settleable solids 25 ml. per liter. The flow into the plant is fairly constant throughout the day. High flows and variable characteristics do occur but are normal conditions.

The first units of the plant are two aerators followed by two primary clarifiers having detention times of approximately 12 hr. and 2 hr. respectively. These units provide the primary treatment for the wastes which are subsequently fed into the heart of the plant. This stone and concrete heart is composed of two 80-ft. diameter high rate biological filters containing 1.39 acre ft. of crushed and graded blast furnace slag. Each filter is served by a secondary clarifier having the same capacity as the primary clarifiers. Primary and secondary sludges are conditioned with ferric chloride and lime and are dewatered on a vacuum filter. The resulting cake is disposed on a dump in an isolated area of the property.

The plant was designed for a daily B.O.D. loading of 8,000 lb. in a flow of 111 g.p.m. In the beginning, the hydraulic loading was from 50 to 100 per cent over the design flow. This high flow was due to vacuum pump seal water that had a low B.O.D. of approximately 100 p.p.m. This low strength and high volume flow was diverted to the chemical waste sewers and since then the loadings both hydraulic and B.O.D. have ranged from 50 to 75 per cent of the design figures. The B.O.D. of the influent varies from 3,000 to 9,000 p.p.m. with an average of 4,500 p.p.m.

When operation was started, an effort was made to control the pH with automatic equipment and to keep it between 6.8 and 7.2. The automatic equipment required considerable at-

tention and, after it was learned that the influent pH would vary only between 6.0 and 7.5 with an average of about 6.8, the use of the neutralizing equipment was discontinued. All variations of pH are averaged out by the excellent mixing and compositing action of the aerators.

The aerators designed for 12 hr. detention have proven to be very valuable units. The compositing action and the vigorous aeration serve to condition the wastes for further treatment. The full air capacity has been used continuously thus providing from 5 to 7 cu. ft. of air per gallon of influent. Little effort has been made to reduce this air volume in the belief that the more air supplied to this high B.O.D. waste the better the results would be.

Operation

The most satisfactory method of opperation that has been found to date is the return of trickling filter sludge to the aerator. When the trickling filter biota are in a good state of health the sludge from the secondary clarifiers is continuously returned to the inlet of the aerators. These active organisms that have sloughed off the trickling filters serve as seed and help build a biological floc in the aeration tanks. This floc will ordinarily contain 2 to 5 per cent settleable solids by volume. The floc concentration depends on the strength of the liquor in the aerators. The weaker the liquor, the more concentrated the floc. When starting up the aerators after shutdown periods it is helpful to have a weak waste in the aerators either sanitary sewage or diluted normal wastes.

The evaluation of the aerator performance was at first puzzling and a bit confusing. Samples of the aerator influent and effluent were taken in an effort to measure B.O.D. reduction through the units. But on many occasions, the effluent B.O.D. would be greater than the influent B.O.D. The effluent sample always showed a high concentration of settleable solids due to the floc present in the aerator. Since this floc had absorbed some of the organic matter from the waste it exerted quite a B.O.D. when tested. The procedure of evaluating the aerators and primary clarifiers as a unit was then adopted. The biological floc from the aerator settles in the clarifiers, leaving a relatively clear and solids free liquor. The B.O.D. reduction through these two units has been from 30 to 75 per cent with an average of about 50 per cent.

This range is provocative of thought and the opinion based on present information is that the health and the balanced population of the biofilters are directly interrelated to the behavior of the primary aeration unit. The returned sludge from a healthy biofilter exerts a beneficial effect on the primary aerator. The settled aerator effluent, in turn, has a beneficial effect upon the biofilters.

If, on the other hand, sickly and attenuated organisms are returned to the primary aerator it in turn does a poor job. This results in the application of an effluent of poor quality to the biofilters. Thus a vicious cycle is set in motion and, unless broken by corrective action, may result in the death of the biofilters. This has occurred twice in this plant. The stench is indescribable, and the problem of disposing of the deluge of sludge becomes quite formidable. Sometimes this sludge, resulting from the annihilation of millions of organisms, becomes gooey and will not dislodge from the filters. This presents the even more difficult twin problems of odors and dislodgement. To experience one of these occurrences is to fully appreciate the value of a balanced biological community in the trickling filters.

The 16-ft. diameter primary clarifiers do a good job at design flow, but are very sensitive to hydraulic overloading. This limitation of size was imposed as a design factor by the fact

that the freshly settled solids from similar liquors at the American Cyanamid Company Pearl River Plant displayed rank putrefactive characteristics. Engineering judgment pinpointed the primary clarifier capacities. The removal of lard oil, an essential process in connection with this type of fermentation operation, is handled by gravity separation as planned in the original design.

Operational Problems

The real problems have been with the biofilters. Several methods of operation have been tried and, in each case the methods used were directed toward building up and maintaining a healthy growth in the biofilters. It must be regretfully reported that many methods of operation were not successful. In fact, up to this time no method has given sustained high efficiency. It is well recognized that bacteria are ubiquitous and that the biological population in a waste treatment plant is a result of environmental conditions prevailing in the trickling filters. The rigid control of conditions available and used in a production operation do not apply in effluent treatment. This is because a waste treatment man must take whatever is sent to him and must build up a biological population which will thrive on the waste products.

Biological Activity

The plant was started late in the summer of 1952 and, although the usual startup troubles were present, it was not long until good B.O.D. reductions were being obtained. These high reductions continued until midwinter when the biological life on the filters seemed to die off and by March, 1953, B.O.D. reductions were down to a miserable low of 18 per cent. The filter media was black and bare, and it appeared that there was no biological life in the filters. Most of the time during this period, the filters had been operated in parallel with low recirculation rates. In April, May, and June various other methods of operation were tried, yet even with the warmer weather of May and early June B.O.D. reductions were still averaging only 37 per cent. Late in June a new combination of series operation was tried, using approximately 2 to 1 recirculation and the continuous return of secondary sludge to the aerators. The long lost biota returned to the trickling filters and flourished in fine style. This started a period of operation during which the B.O.D. reductions averaged over 90 per cent.

As shown in Figure 1 these good reductions prevailed until December 1953 when a deterioration in the state of health of the biota was apparent. During January, February, and March 1954, B.O.D. reductions dropped to a monthly average of 57 per cent. It was theorized at that time that the lower filter temperatures prevailing during the winter were responsible. However, experience showed that this was not the case. The B.O.D. efficiency remained at a very low level even though the warmer weather of April and May raised the filter temperatures. At this point, it was realized that the filters were afflicted with a serious illness other than low temperatures. This ailment was soon diagnosed as being severe clogging of the beds. Air and liquid passages through the biofilters were choked off by masses of black jelly-like dead zooglea. This life-destroying accumulation was apparently the remains of the thick, lush biological growth that had prevailed on the filter since the previous summer.

Filter Media

Principal cause for the retention of this biological refuse on the filters was the disintegration of the filter media into smaller pieces, resulting in smaller void spaces. Crushed blast furnace slag, which has proved to be a completely satisfactory filter media

in many municipal and industrial trickling filters, was used in these biofilters. Grading was carefully checked by the supplier of this slag and many precautions were taken in the handling and placing. However, pieces of slag on the filter had distintegrated by splitting into smaller pieces or had softened into putty-like masses (Figure 2). This is a serious condition which may in time necessitate the rebuilding of these units. There is no apparent reason for this disintegration. On the basis of this experience it appears that crushed blast furnace slag is not a satisfactory and durable media for biofilters treating fermentation wastes.

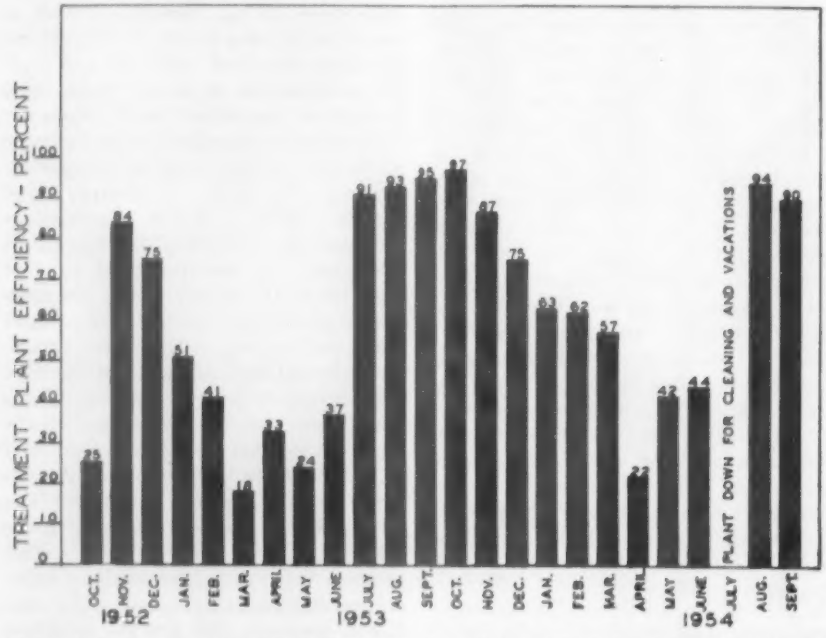

FIGURE 1.—Average monthly B.O.D. reductions through the industrial waste treatment plant of American Cyanamid Co., Willow Island, W. Va.

To obtain some idea of the extent of this disintegration, test trays (Figure 3) were placed on the filter beds and are being checked periodically. Each tray was filled with 60 sound, large size pieces of slag and after 7 months of exposure, there had been a 7 per cent increase in the number of pieces of slag in the trays. Figure 4 shows the condition of the beds when the test trays were being placed. When the slag was dug away to place the trays it appeared that the disintegration was only in the top 1½ to 2 ft. of the 6-ft. depth of the bed. If this is the case, the useful filter life may be extended by removing the top 2 ft. of slag and using a 4-ft. depth of bed. Experience at the Pearl River facilities indicates that 4-ft. beds are adequate for these wastes.

Slime Removal

The removal of tons of dead slimes clogging the filters was the next item for consideration. Caustic was tried first on one of the clogged filters to cause it to unload. The application of 2,700 lb. of caustic proved to be a waste of time and money because

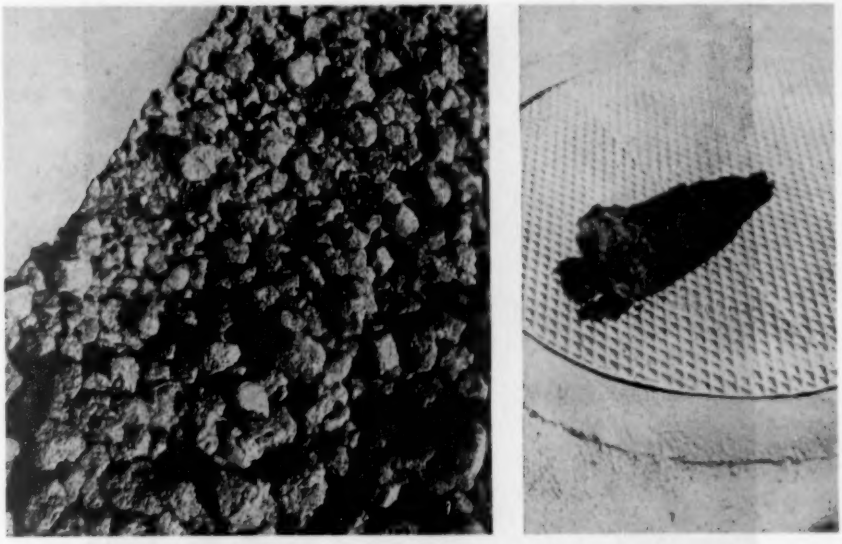

FIGURE 2.—Disintegration of filter stone into small pieces (left) or by softening (right).

the jelly-like slimes were not freed from the slag and the clogging persisted. These slimes had a strong buffering effect and the applied volume of caustic only raised the pH from 7.5 to 8.2. Since it appeared that a high, lethal pH condition could not be practicably obtained by adding caustic, 2 p.p.m. of cyanide nitrogen as sodium cyanide were applied to the recirculating liquor. After this treatment microscopic examination of the biota indicated that few living organisms remained. In spite of this mass poisoning of the living organisms on the biofilter, the clogging, jelly-like, odorous mass remained tenaciously adhered to the filter media.

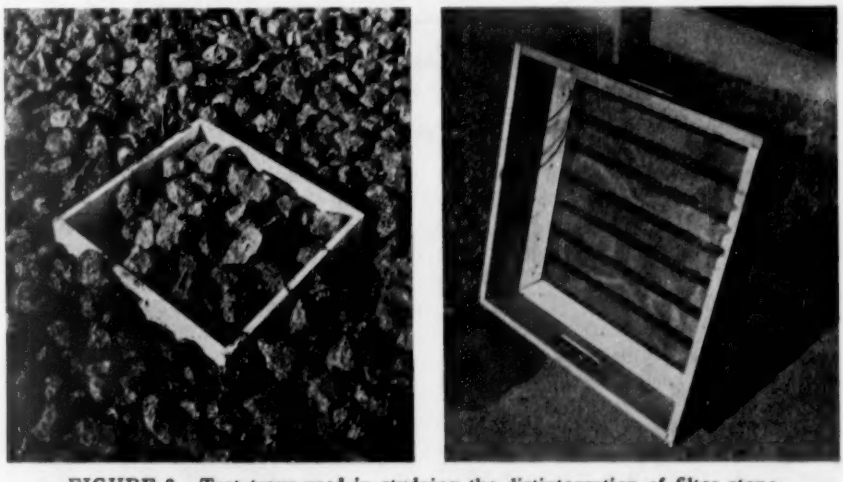

FIGURE 3.—Test trays used in studying the distintegration of filter stone.

FIGURE 4.—Condition of filter stone when the test trays were placed. Note the mass of dead zooglea clogging the voids between the pieces of slag.

It was therefore felt that no practical chemical treatment could remove this dead mass of material and some physical method must be tried. By using an unnozzled fire hose, large volumes of water were applied to small sections of the filters and the hydraulic sluicing action of the water carried away the clogging material.

After the cleaning was accomplished the filters were dried for two weeks during the annual vacation period shut-down of the manufacturing facilities. Operations were started again about August 1, 1954, and from the beginning B.O.D. reduction through the entire plant has been high. It seemed apparent that once again there was a healthy biological population in the treatment plant.

The operating conditions since August have been typical of the treatment that has been accomplished with this plant under favorable conditions. The B.O.D. loading has been 5,500 lb. per day (5,700 p.p.m.) in a flow of .090 m.g.d. Over-all B.O.D. reduction has averaged better than 90 per cent. Suspended solids removal in the plant has been about 65 per cent. Reductions in B.O.D. through the aerators and primary clarifiers have averaged 60 per cent. The B.O.D. loading on the primary biofilter has averaged 2,800 lb. per acre ft. per day (2,000 p.p.m.) and 1,300 lb. per acre ft. per day (900 p.p.m.) on the secondary filter. Each filter has been removing approximately 60 per cent of the applied B.O.D. Recirculation rates are 1½ to 1 on both filters.

These loadings and operating conditions are generally the same as those that prevailed in the summer of 1954 during the period of good B.O.D. reductions. The problem now will be to maintain these healthy conditions for an indefinite period.

Summary

It is apparent that there are a number of factors to be considered and evaluated in connection with the operation of aerators and trickling filters

treating fermentation wastes. Among these are:

1. A primary aerator can, if properly and continuously seeded, be a valuable tool in the treatment of high strength fermentation waste liquors.
2. Series operation of the biofilters will result in the highest over-all B.O.D. reductions.
3. B.O.D. loadings as high as 5,000 lb. per acre ft. per day may be applied to biofilters. Sustained loadings of this magnitude may result in clogging of the filter and, in extreme cases, the subsequent death of the filter growth.
4. Periodic changes in the nature and extent of the food supply to the filter biota will tend to decrease the magnitude of growth and lessen the detrimental clogging conditions.
5. Blast furnace slag is apparently attacked by the fermentation waste and caused to disintegrate.
6. Most important, a biological treatment plant must be inhabited throughout by a healthy community of organisms. The biological degradation of any one treatment unit of the plant will lead to the failure of the other plant units if quick corrective action is not taken.

Reference

1. Vogler, J. F., Brown, J. M., and Griffin, C. E., "Chemical and Antibiotic Wastes Treatment at Willow Island—A Symposium." THIS JOURNAL, **24**, 4, 485 (Apr., 1952).

INTERESTING EXTRACTS FROM OPERATION REPORTS

"Anger is a wind which blows out the lamp of the mind"—Anon.

Attention operators! It will be appreciated if copies of all annual reports of both large and small plants are sent to the Federation office for abstracting in this section of the Journal. Carbon copies of typewritten reports will be promptly returned on request. Please direct annual reports to: Federation of Sewage and Industrial Wastes Associations, 4435 Wisconsin Ave., N.W., Washington 16, D. C.

Report on the Operation and Maintenance of the Easterly Sewage Treatment Plant, Cleveland, Ohio, for the Years 1952 and 1953 *

BY JOHN J. WIRTS, *Superintendent*

General

This sewage treatment plant, the largest of the three plants in Cleveland, treated an average of 102 m.g.d. of the total sewage flow of 180 m.g.d., accomplishing better than 90 per cent removal of suspended solids and B.O.D. Quality treatment is imperative because the treatment plant grounds and adjacent lake front are used for recreation.

During 1952 and 1953 shift supervision continued to be a critical problem with the average number of full time employees at 57.

A special test on spent caustic solution from a refinery was conducted in 1953 to find a suitable method of disposal. Some success was experienced in adding 1 part caustic to 700 parts of 3 per cent activated sludge.

* For last previous extract see THIS JOURNAL, **25**, 9, 1108 (Sept., 1953).

Mixing with concentrated activated sludge formed a precipitate of iron sulfide.

The average flow of the low level Collinwood interceptor has increased 51 per cent during the period 1934–1953. Rates of flow at the plant approach 150 m.g.d. and plant capacity has not been changed since originally constructed in 1938.

The increase in operating costs is attributed to a steady increase in the cost of supplies and services.

Comminutors and Detritors

Routine replacement of the comminutor cutting elements maintained the units at peak efficiency. Most of the replacements were from stock reconditioned in the plant's machine shop. The installation in 1953 of the fourth new comminutor completed the replacement program started in 1947.

Operation of the grit removal equipment, detritors and grit chambers, continued on an "as need basis." Traction wheels on detritors No. 1, 2, and 3 were replaced in 1953 with chilled iron. A similar replacement on Unit No. 4 in 1952 lengthened the wheel life.

Clarification and Grease Flocculation

Beginning in 1953 the conveyor chain was replaced as required. The chain life is estimated at 7 yr. Rustproof grease was placed on all chain as an experiment in the effectiveness of the grease in preventing corrosion.

Heavy fuel oil accumulated to a depth of 6 in. on the surface of the primary tanks during January and February, 1952. Grease skimming devices were completely ineffective in removing waste of this consistency. The tar-like mixture was finally pumped to the adjacent lawn with a diaphragm pump. Later it was removed to the grit dump using a crane and bucket.

All pre-cast concrete ridge and furrow segments were removed in 1952 from the grease flocculation tank bottoms. Very crude Dox Plank diffusers were tested in tank No. 3. Results were so successful that Dox diffusers were installed in the No. 4 tank, replacing the drilled pipe diffusers. Fine grit and silt accumulate inside the drilled pipe diffusers rendering them practically useless.

Aeration

Maximum lake elevations during 1952 presented a serious hydraulic problem in the operation of the aerators. Complete submergence of the baffles resulted and it was almost impossible to maintain adequate D.O. in the units.

Replacement of the pitted cast aluminum air manifolds was completed in 1952. Steel frames and manifolds rusted badly in a short period of time. The program of dismantling, cleaning, and fitting the plug valves with Alemite fittings was completed in 1953.

The entire concrete manifold was found to be porous and air is diffusing through the 18-in. concrete walls and top. Work on the manifold will require shutting down the aeration plant.

The top surface of all diffuser plates was coated with a 5 per cent silicone solution, as an experiment to find what effect silicone has in delaying the clogging of the plates.

Force Main

Maintenance of the 13 mi. sludge force main to the Southerly treatment plant during 1952 and 1953 has been the most difficult on record. The main was completely cleaned 7 times in 1952. Severe blockages caused by fine silt were traced to breaks in a main interceptor tunnel. The contractor building a freeway interchange was considered responsible for the breaks and legal action is pending.

Ten cleanings were necessary in 1953. The pumps, operating against an increased head condition, are not producing sufficient velocity to move the desired concentration of sludge.

It is proposed that the first stage discharge pressure be increased to a maximum within the limits of the existing equipment. Pressures now exceed 200 p.s.i. during periods of heavy sludge pumping and force main cleaning.

Operation data for 1952 and 1953 are summarized in Table I.

TABLE I.—Summary of 1952 and 1953 Operating Data, Easterly Plant, Cleveland, Ohio

Item	Average 1952	1953
Raw sewage flow (m.g.d.)	100.8	101.9
Settled sewage flow (m.g.d.)	91.8	94
Grit removed (cu. ft. per m.g.)	3.8	3.2
Screenings (cu. ft. per m.g.)	.22	.2
Suspended solids (p.p.m.):		
Raw	219	210
Settled	127	126
Effluent	14.3	11.5
Removed (%)	93.4	94.5
B.O.D. (p.p.m.):		
Raw	133	134
Settled	76	79
Effluent	12.1	10.5
Removed (%)	90.8	92.2
Oxygen consumed (p.p.m.):		
Raw	89	97
Settled	63	63
Effluent	25	19
Reduction (%)	71.9	80.4
Dissolved oxygen (p.p.m.):		
Raw	1.5	1.4
Aerator influent	1.8	1.4
Aerator effluent	3.1	1.9
Final effluent	2.2	2.8
Ammonia (p.p.m.):		
Raw	16.1	13.4
Settled	9.8	9.8
Effluent	9.5	9.6
Nitrite, effluent (p.p.m.)	0.3	0.2
Nitrate, effluent (p.p.m.)	0.5	0.3
Sludge pumped to Southerly plant, total (m.g.)	179.39	206.88
Moisture (%)	96.6	96.9
Activated sludge:		
Total solids (p.p.m.)	5,679	5,892
Volatile solids (%)	62.9	63.1
Mixed liquor susp. solids (p.p.m.)	1,284	1,249
Sludge index (ml./gram)	81	114
Air (cu. ft./gal. sett. sew.)	0.84	0.78
Postchlorination:		
Days applied, total	98	90
Application rate (p.p.m.)	3.6	3.6
Residual (p.p.m.)	0.7	1.1
Bacterial count; agar plates at 37½° C. (1,000 per ml.):		
Raw	2,541	3,448
Effluent	169	140
Reduction (%)	93.3	96
Presumptive *B. coli* (1,000 per ml.):		
Raw	116.4	88
Effluent	2.9	1.6
Reduction (%)	97.5	98.2
Plant costs ($ per m.g.):		
Operation and maintenance	19.08	21.40
Administration	12.27	14.15
Total	31.35	35.55

Report on the Operation and Maintenance of the Westerly Sewage Treatment Plant, Cleveland, Ohio, for the Years 1952 and 1953 *

By John O. Barrett, *Superintendent*

General

The average daily flow of 33.8 m.g.d. in 1952 and 33.4 in 1953 was approximately 12 per cent below the record flow of 1950. Diversion of some sewage flow caused by repairs to the interceptor on West 117th Street, following the explosion of September 10, 1953, may have had some effect in reducing the flow.

The need for additional digester capacity has been indicated during the past two years. Effective capacity of the present units is materially reduced by the formation of excessive scum layers averaging 10 ft. in thickness.

Operating conditions of the grit removal equipment were similar to those existing in previous years. During 1953 considerable repair work was required on the rake, mascerator, grit crane, and detritor.

Sedimentation

Imhoff tanks are used for primary sedimentation and every effort is made to remove the solids as fresh as possible. Six digesters handle the solids load. As usual the slots in several Imhoff tanks became blocked during the winter. Considerable digestion took place in the tanks as evidenced by gas escaping through the gas vents and slots. Heavy gas vent scum was sent directly to the filter or the storage tank, and not to the digester as in previous years.

Two of the Imhoff tanks were used for sludge and scum storage as in previous years. Digester scum was handled much more conveniently in 1952. The storage tanks were first pumped down to the slots before adding digester scum, thereby providing room for a greater portion of the heavy scum. Scum from the storage tanks was broken up by water pressure and added daily to the filter sump together with digested sludge. Removal of the digester scum to the storage tanks then followed and was completed during the summer months thus avoiding the undesirable feature of having frozen scum on the storage tanks interfere with the overflow of supernatant from the tanks.

Chlorination

Procedures for chlorinating the sewage continued as in prior years. Prechlorination was utilized again to control odors, bacterial growth, and gas vent foaming. During the recreation season concentrated efforts were undertaken to maintain a chlorine residual in the effluent. The presence of industrial wastes having a high chlorine demand taxed the equipment capacity on several occasions.

Sludge Digestion

Digester operations varied only slightly from those of previous years. Minimum monthly gas production occurred in September and August for 1952 and 1953 respectively. The previous pattern had been October as the minimum month. The rate of gas production has decreased for five consecutive years, being 6.3 cu. ft. per pound of volatile solids added in 1953. The ten year average is 8.3 cu. ft.

Four of the six digester boilers became inoperative during the year due to the rusting of the coils, resulting in leakage.

Late in 1953 an experiment was started on gas recirculation from the gas dome to the supernatant layer below the scum layer. The limited amount of data obtained indicated that the scum was reduced, but the consistency was more dense. Comparison with a digester used as a control

* For last previous extract see This Journal, **25**, 9, 1110 (Sept., 1953).

indicated that additional scum formation may have been prevented.

Filtration

Due to a marked increase in the quantity of sludge processed it was necessary to operate 24-hr. per day. During 1952 one-half of the sludge filtered was pumped directly from the digesters while the balance consisted of sludge and scum from the storage tanks. About one-quarter of the solids were from digester and gas vent scum.

The average life of the filter cloth was only 117 hr. as compared with a 10 yr. average of 211 hr. An extensive experiment was conducted in the laboratory to determine the effect of different sludges on cotton filter cloths. The result of the experiments indicated that the filtering of large quantities of sludge directly from the digesters was the cause of decreased cloth life. The practice was discontinued in 1953 and the average cloth life increased slightly.

Incineration

Incinerator practice continued near normal with the park department and public taking over 80 per cent of the sludge cake. Because of the light service the incinerators have required only a minimum of maintenance.

Operation data for 1952 and 1953 are summarized in Table II.

TABLE II.—Summary of 1952 and 1953 Operating Data, Westerly Plant, Cleveland, Ohio

Item	Average 1952	1953
Raw sewage flow (m.g.d.)	33.8	33.4
Grit removed (cu. ft. per m.g.)	3.1	2.8
Screenings (cu. ft. per m.g.)	0.5	0.5
Suspended solids (p.p.m.):		
Raw	269	277
Imhoff tank effluent	177	181
Removed (%)	34	34.7
B.O.D. (p.p.m.):		
Raw	190	183
Imhoff tank effluent	151	142
Removed (%)	20.5	22.4
Oxygen consumed (p.p.m.):		
Raw	140	145
Imhoff tank effluent	122	129
Reduction (%)	13	11
Total bacteria (1,000 per ml.):		
Raw	2,497	2,471
Imhoff tank effluent	762	904
Reduction (%)	69.5	63.4
Presumptive *B. coli* (1,000 per ml.):		
Raw	508	410
Imhoff tank effluent	101	109
Reduction (%)	80.2	73.4
Prechlorination:		
Days operated	81	86.5
Average dose (p.p.m.)	4.6	4.64
Postchlorination:		
Days operated	83.7	94.8
Average dose (p.p.m.)	5.3	6.1
Average residual (p.p.m.)	1.4	1.4
Raw sludge to digesters:		
Number of additions per month	74	75
Temperature (°F.)	64	65
Volatile solids (%)	63.2	61.4
Total solids (%)	6.5	6.7
pH	6.7	6.6
Alkalinity as $CaCO_3$ (p.p.m.)	890	860

TABLE II.—(Continued)

Item	1952	Average 1953
Digester supernatant:		
Total solids (%)	1.2	0.7
Volatile solids (%)	51.2	50.2
pH	8	7.9
Alkalinity, as $CaCO_3$ (p.p.m.)	2,250	2,010
Gas production:		
Daily production (cu. ft.)	140,700	153,700
Cu. ft. per lb. volatile solids	6.9	6.3
CO_2 (%)	27.4	27.2
Gas utilization (%):		
Digester heaters	28.7	27.4
Building heaters	23.5	22.2
Incinerators	28.4	35.3
Wasted	19.4	15.1
Digested sludge vacuum filtered:		
Total solids (lb. per month)	570,500	590,100
Total solids (%)	8.3	8.6
Volatile solids (%)	51.6	50
pH	7.9	7.9
Alkalinity, as $CaCO_3$ (p.p.m.)	2,180	2,100
Chemical dosage for vacuum filtration (%):		
Ferric chloride	2.8	2.9
Lime	14	15.1
Calcium oxide	12.5	13.4
Sludge filtration:		
Filter cake:		
Total (tons)	11,581	13,217
Moisture (%)	65.9	66
Volatile solids (%)	44	43.5
Pounds dry solids per sq. ft. filter area per hr.	3.8	3.5
Filter cake per filter hour (tons)	0.9	0.85
Average filter cloth operating life (hr.)	117	126
Sludge filter cake:		
Tons per month incinerated	162	376
Tons per incinerator hour	1.1	0.86
Tons used for soil conditioner	9,632	8,702
Incineration:		
Fuel oil used:		
Gal. per ton of filter cake	0.17	0.54
Gal. per ton of dry solids	0.48	1.56
Gas used:		
Cu. ft. per ton of filter cake	878	1,694
Cu. ft. per ton of dry solids	2,500	4,876
Plant costs ($ per m.g.):		
Operation and maintenance	15.17	16.37
Administration	12.32	14.04
Total	27.49	30.41

Report on the Operation and Maintenance of the Southerly Sewage Treatment Plant, Cleveland, Ohio, for the Years 1952 and 1953 *

By Walter E. Gerdel, *Superintendent*

General

A major construction program was undertaken during 1952 and 1953 primarily involving additional digesters and elutriation equipment, and new primary settling tanks and aerators. The construction work interfered somewhat with regular routine plant operation and required special procedures to be observed at all times.

* For last previous extract see This Journal, **25**, 9, 1113 (Sept., 1953).

In addition, considerable breaking in and testing of new equipment was necessary.

The trickling filters were operated only during May, 1952, after which they were permanently abandoned due to ponding and poor results caused by the clogged condition of the stone. The following distribution of sewage flows applies to the effluent from the Imhoff tanks:

Distribution	Flow (%) 1952	1953
To aeration tanks	54.1	52.5 [1]
To trickling filters	3.3	0.0
By-passing sec. treat.	42.6	47.5

[1] excluding elutriation

The continuing increase in cost of operation during these two years was caused mainly by wage and salary adjustments.

The metered raw sewage flow was 14,037.8 m.g.d. for 1952 and 13,180.7 m.g.d. for 1953. This represented a substantial increase over the previous year due to the end of construction activities that had caused diversion of the Big Creek interceptor flow. The lower figure for 1953 is attributed to necessary plant by-passing in November as a result of construction work. A temporary chlorinating station was set up for the by-passed sewage.

Primary Treatment Units

Newly constructed primary settling tanks were put in service in November, 1953, replacing the Imhoff tanks. The latter were converted to open type secondary digesters with satisfactory results.

Principal operating problem was the accumulation of an industrial waste oil on the Imhoff tanks. Minor difficulties developed in placing the new settling tanks in operation.

Aeration Units

With an air volume of approximately 0.5 cu. ft. per gallon of influent flow, the aerators showed B.O.D. reductions of 67.2 per cent and 71.1 per cent for 1952 and 1953 respectively. The effluent is given no further treatment and is the source of supply for the wash water used for elutriation. Earlier poor operating results due to the return of elutriate water to the aerators were not evidenced in 1953 and excellent results were obtained, although there was an increase in the solids loading.

A main electrical conduit failed in September, 1953, apparently due to water that had lain in the conduit since the 1948 flood. Gas engine blowers operated satisfactorily, requiring only one engine to carry the load. The No. 2 engine underwent a major overhaul in 1953.

Sludge Digestion

Sludge concentration was confined to waste activated sludge from this plant. The volume, however, had increased 70 per cent in 1953 due to sludge elutriation. Provision was made in 1952 to pump sludge from the Easterly plant directly to the digestors. As a result, odors in the concentration unit were greatly reduced. Late in 1952 six new digestion tanks and auxiliary equipment were placed in operation to supplement the 12 old tanks. The effect of additional digestor capacity and improved sludge heating facilities was clearly indicated by a 50 per cent increase in gas volume. The average supernatant temperature rose from 67° F. in 1951 to 86° F. in 1952. The supernatant is recirculated through the external sludge heaters when raw sludge is not being added.

The 12 old digesters were cleaned in a project that took place from March 24 to September 5, 1952. Elutriation wash water, boosted in pressure, was utilized in the cleaning operations.

Experimental work on utilizing the concentration tanks to settle digester supernatant liquor indicated that the tanks were only effective when the liquor contained 1.5 per cent or less total solids.

TABLE III.—Summary of 1952 and 1953 Operating Data, Southerly Plant, Cleveland, Ohio

Item	Average 1952	1953
Raw sewage flow (m.g.d.)	38.4	36.1
Screenings (cu. ft. per m.g.)	0.42	0.66
Grit (cu. ft. per m.g.)	1.24	1.3
Per cent volatile	59.2	55
Flow distribution, total (m.g.):		
Aeration unit	7,595.3	6,257.3
Trickling filters	460	—
By-passing sec. treat.	5,982.5	6,923.4
Suspended solids (p.p.m.):		
Raw	191	192
Imhoff tank effluent	134	146
Aerator influent	142	157
Aerator effluent	55	44
Dissolved oxygen (p.p.m.):		
Raw sewage	5.3	4.8
Imhoff tank effluent	1.7	2
Aerator effluent	1.3	0.7
River above plant	6.8	6.8
River below plant	6.7	6.2
B.O.D. (p.p.m.):		
Raw	118	138
Imhoff tank effluent	64	86
Aeration tank effluent	21	24
River above plant	6.9	7.8
River below plant	11.7	21.8
Combined effluent over-all reduction (%):		
Suspended solids	52	56.9
B.O.D.	65.2	61
Sulfates in raw sewage (p.p.m.)	188	232
Digester operation:		
Raw sludge:		
Volume, total (m.g.)	209.3	259.6
Per cent from Easterly plant	85.7	80.2
Per cent from Southerly plant	14.3	19.8
Dry solids (mil. lb.)	56.3	64.5
Volatile solids (mil. lb.)	35.7	40.3
Digested sludge:		
Volume, total (m.g.)	35.4	47.9
Dry solids, total (mil. lb.)	19.3	18.1
Volatile solids, total (mil. lb.)	9.1	8.6
Total solids (%)	5.4	4.4
Volatile solids (%)	47.4	47.5
Alkalinity (p.p.m.)	3,260	3,160
pH	7.5	7.6
Supernatant:		
Volume, total (m.g.)	178.7	210.9
Total solids (%)	1.6	1.1
Volatile solids (%)	54.8	51.8
Suspended solids (p.p.m.)	10,921	8,855
Gas production:		
Daily production (cu. ft.)	654,000	867,000
Cu. ft. per lb. volatile solids	6.6	7.9
CO_2 (%)	33.2	34.4
B.t.u. (gross)	617	583
Gas utilization (%):		
Wasted	27.2	25.7
Digester heating	34.8	43.1
Incinerators	11.6	8.3
Gas engines	19.8	14.7
Building heat and misc.	6.5	8.2

TABLE III.—(Continued)

Item	1952	Average 1953
Vacuum filtration of sludge:		
Filtered, total (m.g.)	38.8	56
Dry solids, total (mil. lb.)	19.7	24.3
Chemicals used (%):		
Ferric chloride	5.4	4.7
Lime	17.1	14.5
CaO	15.3	3.2
Filter cake production:		
Dry solids, total (tons)	12,957	16,313.7
Solids (%)	28	28.5
Volatile solids (%)	38.9	39.3
Filter rate (lb. dry solids per hr. per sq. ft. filter area)	3.1	2.7
Filter cloth life (hr.)	364	324
Sludge incineration:		
Tons per month	3,783	4,517
Tons per incinerator hour	3.1	2.9
B.t.u. per lb. volatile solids	11,916	12,161
Filter cake moisture (%)	72	71.5
Filter cake, volatile (%)	38.9	39.3
Plant costs ($ per m.g.):		
Operation and maintenance	18.31	16.69
Administration	12.30	14.05
Total	30.61	30.74

Sludge Disposal

The new elutriation tanks were completed in the spring of 1952. Results of operations to date have not been satisfactory. Efforts were made to use four volumes of wash water to one of sludge, but variations in the sludge pumping rate made this impossible. A heavy scum on the surface of the washing tanks was also troublesome. The process had the effect of increasing the total solids only slightly, and reducing slightly the volatiles.

Efforts to eliminate the use of lime when filtering the elutriated sludge were unsuccessful, unless the ferric chloride dosages were quite high. Laboratory tests and experimentation indicated that it was cheaper to use both lime and ferric chloride than it was to use only ferric chloride. The filtration of elutriated sludge led to higher vacuums being attained in the piping systems and some difficulty with the filtrate pumps. The average life of the filter cloth in 1952 was 364 hr. and 324 hr. in 1953.

A coil type vacuum filter was operated experimentally during October and November, 1953. Although conditions were not ideal, due to various mechanical and chemical feeding troubles, the filter operated on a number of runs in parallel with one of the existing filters. In general, the coil filter out-produced the control filter in dry solids yield, but the cake was appreciably wetter.

The sludge drying beds have not been fully utilized during the past two years due to a manpower shortage and high cost of operation. The beds were taken out of service in June, 1953 and placed on a standby basis in event of major breakdowns of the vacuum filters or incinerators.

Incinerator smoke control has been a major problem. Serious efforts were made in 1953 to operate the incinerators more effectively. Considerable repair and maintenance was necessary on the hearths, but future improvements are expected.

Operation data for 1952 and 1953 are summarized in Table III.

WILDLIFE ESCAPE RAMPS

By Russell Grinnell

Superintendent, Sewage Treatment Plant, Birmingham, Mich.

Undeveloped areas some distance removed from the hub of city life usually are chosen as the most practical sites for sewage treatment plants. These unused areas surrounding many of our cities provide excellent cover for wildlife. Although generally not the habitat for wolves, bear, or deer, the smaller animals such as raccoons, opossums, rabbits, and muskrats are quite common, including a dog or two on a hunting expedition.

Many of these animals are attracted by the water in the sewage treatment tanks, particularly the aerators. Once in they seem to be unable to get out. Aside from the humanitarian reasons it means getting a pole and a scoop to remove their dead bodies. The task of disposing of these hapless creatures is not one that elicits volunteers from the plant staff. However, if the bodies are not discovered soon enough they are drawn into the return sludge pumps and clog them.

FIGURE 1.—Escape ramp for wayward wildlife that fall into the sewage treatment tanks.

At the Birmingham, Mich. sewage treatment plant, which is located in an attractive wooded area, even the cyclone type fence does not keep out the neighboring fauna. Figure 1 shows a float ramp that affords an avenue of escape for animals who have become immersed in sewage. It is easy to see (Figure 2) how the ramps are constructed. The cleated plank is hinged to a simple frame that fits over the top of the tank walls. A painted float of 2 by 4's keeps the lower end of the ramp floating. Although covered with several coats of paint, the float in time becomes waterlogged and has to be replaced. The hinged upper end keeps the ramp in proper position irrespective of the tank water level.

FIGURE 2.—Float ramp is easily constructed from scrap material.

Several of these floats have been installed by plant personnel in strategic locations. Although there have been no reported observations of any animal coming up the ramp there has been a definite decrease in the number scooped out.

TIPS AND QUIPS

Purple, Orange, and Blue

A new revised color code was released to industry recently. It uses three new colors to warn workers against potential dangers, including a high-visibility *purple* to indicate radiation hazards. The other new colors are: *orange* to designate dangerous dangerous parts of machines or energized equipment, and to emphasize dangers for exposed or unguarded parts of machines; and *blue* as a warning against operating machines while under repair.

X-ray Televising

Pump action can be studied through x-ray televising recently developed at the Nation Bureau of Standards. Washington, D. C. The use of high-penetration radiation and a technique for converting the high-energy x-rays into visual images provides a clear picture of moving parts. It should be possible to televise the internal operation of a wide range of mechanisms.

Liquid Zinc

The advantages of "hot dip" galvanizing with none of the expense or inconvenience is claimed by the manufacturer of Zinktron. This laboratory developed method of surface protection is as easily applied as paint. Any iron or steel surface new, old, or deteriorated can be protected with a minimum of preparation, and previously galvanized surfaces can be touched up. A galvanizing action takes place, preventing rust creep.

Developed by Constad Laboratories, information can be obtained from Haldar Sales and Co., 277 Broadway, New York, N. Y.

Filter Fabrics

An interesting illustrated booklet entitled "Filter Fabric Facts" summarizes a number of general and specific points about filter fabrics. The booklet makes no claim to being a complete technical manual, but it does present interesting information on fabric materials and construction.

It will make interesting reading to operators who have filtering equipment. Copies may be obtained from Wellington Sears Co., 65 Worth St., New York, N. Y.

Fish and D. O.

Fish require more dissolved oxygen to survive in turbulent water than they do in still water, according to studies made by the Robert A. Taft Sanitary Engineering Center, USPHS.

Technicolor

Color combinations which focus attention on the recording chart have been introduced by the Bailey Meter Company, Cleveland, Ohio. Gray, green, and tan colored recorders are mounted on panels of the same but lighter shades of color. Fast and accurate instrument readability with minimum operator fatigue are claimed for the new colors.

Anything goes in an effort to ease the strain on operating personnel and bring some color into the treatment plant. How about vermilion colored recorders with pink charts and pale yellow panels!

Clamps Provide Pipe Repair

During the rehabilitation of a sewage treatment plant a 24-in. diameter cast-iron elbow was discovered split as a result of water freezing in the elbow-trap. Replacement would re-

quire weeks and a major operation would be necessitated, critically delaying the rehabilitation program.

Several attempts to repair the elbow failed. Finally, Punch-Lok open-end heavy-duty clamps were applied and successfully pulled to split together so that leakage was negligible. Although the repair was at first considered to be temporary, the elbow is still tight after five years of service.

A pocket-size booklet "Clampways Ideas" can be obtained free of charge from the Punch-Lok Company, 321 N. Justine St., Chicago 7, Ill.

Guide to Community Safety Programs

A "how to" guide setting forth steps in organizing an effective community safety program is available. Prepared by the Committee on Community Safety Programs of the President's Conference on Occupational Safety, the guide recognizes community action as an effective means of preventing work accidents, many of which occur in the smaller plants.

The guide includes a sample program for a one-day community safety conference and a list of sources of help for groups wishing to organize a conference. A limited supply of the guide is available without charge from the Bureau of Labor Standards, U. S. Department of Labor, Washington 25, D. C.

Here is an opportunity for sewage treatment plant personnel to extend their safety consciousness into the community.

5,500,000 Fish

Eleven fish per cubic feet, each fish averaging slightly less than 6 oz. in weight, resulted in a mass death in the Upper Lane Cove River at Sydney, Australia. Lack of oxygen and high phosphates were noted in the 11 acre-ft. of available water.

Non-Oily Penetrant

Corroded nuts and bolts that will not respond to diligent efforts of a wrench can now be eased into cooperation.

A new product, the first non-oily penetrant, has been announced by Olin Mathieson, Chemical Corporation. Reported to be more effective than oils, it is fast acting, deep penetrating, and safer to use because it is nonflammable and does not spread over the work.

The new penetrant is distributed by National Automotive Parts Association jobbers under the name Puritan Penetrant.

Instructor for Lebanon

Word has been received from Biblical Lebanon that an instructor in sanitary engineering is needed in the new Public Health School at the American University of Beirut. The position carries an income tax free salary of $6000 per year together with round trip transportation. Further information may be obtained directly from A. E. Williamson, Jr., Chief, Public Health Staff, American Embassy, Beirut, Lebanon.

Federation Affairs

ATLANTIC CITY MEETING PLANS NEAR COMPLETION

Atlantic City, New Jersey, will be the locale of the 28th Annual Meeting of the Federation of Sewage and Industrial Wastes Associations to be held October 10–13, 1955. This city, with attractive hotel and convention accommodations, will provide excellent facilities for the technical sessions, the manufacturers' exhibits, and enjoyment of the environment by all who attend. The opportunity for combining attendance at the meetings with additional time for relaxation before or after the meeting is most inviting.

Committee members of the Local Host Association—the New Jersey Sewage and Industrial Wastes Association—have been hard at work on final details for the meeting, which the Host Association promises to be the largest in Federation history.

Local Committees

The Local Arrangements Committee, under the general chairmanship of Mr. Sol Seid, Supervisor, Department of Public Works, New Brunswick, New Jersey, is composed of the chairmen of the following subcommittees:

Registration Committee: Andrew Palmer, chairman; W. S. Applegate, C. Molitor, C. B. McMannamin, W. H. Higgins, M. S. Kachorsky, R. J. Budrick, A. Scocco, and W. J. Fairbrother.

Hotel Arrangements Committee: H. C. Greenfield, chairman; R. B. Mowry, W. Gross, M. Brunstein, and A. Leahey.

Finance Committee: P. N. Daniels, chairman; C. Ellis, C. D. Morelli, and L. Morrill.

Entertainment Committee: J. Horgan, chairman; J. Stewart, D. Gallagher, and C. Bessen.

Ladies Entertainment Committee: Mrs. A. Clark, chairman; Mrs. S. Seid, co-chairman; Mrs. M. Brunstein, co-chairman; Mrs. M. Kachorsky, Mrs. H. Van Der Vliet, Mrs. J. Horgan, Mrs. L. Fontenelli, Mrs. F. Van Orden, Mrs. H. P. Croft, Mrs. P. N. Daniels, Mrs. R. Mowry, Mrs. J. Collom, Mrs. H. C. Greenfield, Mrs. A. H. Fletcher, Mrs. L. F. Frazza, Mrs. R. Shaw, Mrs. L. Klockner, Mrs. A. Palmer, and Mrs. J. Hood.

Local Host Committee: J. LeChard, chairman; G. A. Scheiter, E. Steelman, J. Moncrieff, G. Fieldhouse, and A. Macri.

Early Registration

To help early arrivals avoid the Monday morning registration rush on October 10, the Registration Desk will be open in the foyer of the Embassy Room of the Ambassador Hotel from 9 AM to 5 PM on Sunday, October 9. All who arrive during this period or before are urged to take advantage of these early periods for registration.

Announcement to Membership

The formal announcement of the meeting was sent to all active and corporate members of the constituent associations of the Federation several weeks ago. That announcement contains further details as to technical and social programs, registration, manufacturers' exhibits, cost of the various functions, and a reservation card for hotel accommodations. Room reservations for hotel accommodations should be made directly with the headquarters hotel, the Ambassador. Anyone desiring additional copies of the formal convention announcement or hotel reservation cards may obtain them from the headquarters office of the Federation.

As the new Atlantic City Sewage Treatment Plant will be in the very early stages of construction, no organized inspection trip is planned to see this plant. However, the Host Association has made arrangements with plants of exceptional interest in the area that are certain to attract many who attend the meeting. As a result, the technical sessions of the meeting will extend over four full days, Monday through Thursday, concluding Thursday afternoon with a symposium on research in the sewage and industrial wastes field.

Reviews and Abstracts*

Waste Disposal at a Steel Plant: General Problems. By Ross Nebolsine. *Proc. Amer. Soc. Civil Eng.*, **80,** Separate No. 492 (Sept., 1954).

This is the first of a group of reports and gives only general information on the problems at the Fairless (Pa.) Works of the U. S. Steel Co., and the basic features in the design of the collection and treatment facilities for industrial wastes.

W. A. Hasfurther

Waste Disposal at a Steel Plant: Treatment of Sheet and Tin Mill Wastes. By Hugh MacDougall. *Proc. Amer. Soc. Civil Eng.*, **80,** Separate 493 (Sept., 1954).

This report gives in fair detail the types and volumes of acid, alkaline, plating, and oil wastes, and the design and operation of the collection and treatment facilities. Insoluble oils are removed in a separator, and soluble oils are first broken by acid so that much will float, then treated with chemicals to remove additional oil that will be absorbed in the precipitate and then either settle or float. Waste pickling acid, waste sodium orthosilicate, and milk-of-lime are used.

Chromium wastes are reduced with spent pickle liquors and then combined with other flows and milk-of-lime added to complete the reaction.

W. A. Hasfurther

Waste Disposal at a Steel Plant: Treatment of Flue Dust Waste. By Angus D. Henderson and J. J. Baffa. *Proc. Amer. Soc. Civil Eng.*, **80,** Separate No. 494 (Sept., 1954).

Wastes resulting from the wet scrubbing of blast furnace gas are settled in a primary thickener, and then given secondary treatment to maintain good water quality in the Delaware River. In the secondary process lime slurry is added in a flash mixer and the waste is then flocculated and settled. Wet washer flue dust contains about 1,200 p.p.m. suspended solids and this is reduced to less than 50 p.p.m.

W. A. Hasfurther

Waste Disposal at a Steel Plant: Treatment of Sewage. By John J. Baffa. *Proc. Amer. Soc. Civil Eng.*, **80,** Separate No. 495 (Sept., 1954).

The plant was designed to remove 85 per cent of the B.O.D. and compensate for conditions of low or no flow on holidays or shutdown periods, and wide and sudden variations in flow and quality. Treatment consists of comminution, settling, filtration on parallel trickling filters, and final settling with underflow from the secondary continuously recirculated.

W. A. Hasfurther

Garbage Reduction: Report of a Subcommittee of the Committee on Refuse Collection and Disposal. *Proc. Amer. Soc. Civil Eng.*, **80,** Separate No. 498 (Sept., 1954).

Various methods of garbage reduction are reviewed and the Merz, Arnold, Chamberlain, Cobwell, Cobwell-Merz, and Morrison processes are described. The processes are compared and reasons given for the decline to only a few existing plants in operation. W. A. Hasfurther

Incineration: Report of a Subcommittee of the Committee on Refuse Collection and Disposal. *Proc. Amer. Soc. Civil Eng.*, **80,** Separate No. 497 (Sept., 1954).

Capacities and main characteristics for 53 recent incinerator installations are tabulated. Problems involved in the measurement of refuse are discussed and tonnage is recommended as the only satisfactory unit.

The circular furnace is increasing in

* Please send to Federation headquarters all periodicals, bulletins, special reports, etc., which might be suitable for abstracting in This Journal. Publications of public health departments, stream pollution control agencies, research organizations, and educational institutions are particularly desired. Address such material: Federation of Sewage and Industrial Wastes Assns., 4435 Wisconsin Ave., N. W., Washington 16, D. C.

popularity, but one improvement in stoking grates which should reduce stoking labor and make rectangular units more satisfactory is discussed. Poorly quenched and poorly maintained residue areas depreciate a good incinerator and better planning for residue handling is needed. Fly ash interception in combustion chamber pockets, waste boilers and arrestors is insufficient in many cases. Water washing is still being tried as an improvement. With higher quantities of combustibles currently received, an over-fire air supply should be considered.

W. A. HASFURTHER

Studies on Aeration. I. BY E. B. CHAIN, S. PALADINO, D. S. CALLOW, D. UGONLINI AND J. VAN DER SLUIS. 1st Intern. Symposium on Chemical Microbiology. World Health Org. Monograph, Series No. 10, p. 73 (1952).

The relative efficiency of different aeration devices has been studied quantitatively. The rate of oxygen absorption was measured by following iodometrically the oxidation of sodium sulfite to sodium sulfate in the presence of copper ions; the power absorption of the mechanical agitation was measured dynamometrically.

Comparing the relative efficiencies of different air spargers in the absence of agitation, a sparger of porous material was found to be twice as efficient as a ring sparger with 90 holes with all air flow velocities tested (0.2 to 1 volume of air per volume of liquid per minute). No significant difference in the rate of aeration was observed between a sparger with one orifice and a ring sparger with 90 holes. Agitation considerably increased the rate of aeration. The porous sparger was always more efficient than the ring spargers; with the lowest agitation speed tested (500 r.p.m.) it was three times as efficient, while with higher agitation speeds the difference became less pronounced, but was still significant. There was no difference between the rate of aeration caused by a single-orifice sparger and a ring sparger with 90 holes of a diameter size approximating that of the propeller. A ring sparger with a larger diameter than that of the propeller gave much less aeration because much of the air escaped along the wall of the recipient without being subjected to the dividing action of the propeller blades.

Plotting of power absorption (in watt-hours per liter) against the rate of aeration (ml. of oxygen per 100 ml. of liquid per hour) in a fully baffled system for a propeller of the turbine type showed a straight-line relationship for diameters of which the ratio of the diameter of the vessel to the diameter of the propeller was between 2.22 and 2.68 over the whole range of oxygen absorption tested with air flows ranging from 0.2 to 1.0 volume of air per volume of liquid per minute; a propeller with the diameter ratio 3.1:1 showed linearity in the zone of practical interest (50 to 200 ml. of oxygen per ml. of liquid per hour), whereas with the smallest propeller (ratio 3.6:1) linearity was approached only with the highest air flow.

Agitation in the absence of baffles leads to the formation of a vortex. Although this produces unfavorable conditions for mixing, it can be utilized for efficient and economical aeration without air being injected into the liquid through an air sparger.

Plotting of power absorption against the rate of aeration showed a linear relationship over a wide range with different types of propeller blades. The effect of four variables of the propeller construction on aerating efficiency was studied; that is, inclination, height, number, and length of propeller blades. A turbine-type propeller with a diameter of about one-third of the diameter of the vessel and with eight blades with an inclination of 90° was found to be the most efficient. The height of the blades did not have much influence on the aerating efficiency.

Aeration was most efficient when the propellers rotated at half the liquid height.

With the vortex system, any degree of aeration can be obtained within the limits of practical interest. Comparison of the relative aeration efficiencies of the fully baffled and the vortex systems of aeration showed that for high rates of aeration the vortex system is considerably more economical in consumption and therefore more efficient. The vortex system of aeration has an important advantage over the fully baffled system in that the control of excessive froth formation presents no problem.

A new type of "spargerless" fermenter

has been constructed on the basis of the vortex system of aeration. The fermenter has been used successfully for penicillin fermentations and the production of bacteria. H. HEUKELEKIAN

Water Supply and Sewage Disposal in the Industrial Ruhr District. BY H. ROHDE. Pamphlet, 12 pp. (1952).

The Ruhr River supplies water to a large industrial area for industry and drinking. In 1952 the water taken from the Ruhr was 1,023,000,000 cu. m. (270,277 m.g. U. S.) Of this, 20 per cent was used for approximately 4,500,000 population and 80 per cent for industry. About one-half the water from the Ruhr watershed is used for the Ruhr population and industry. The other half is pumped to other areas, including the Emscher district.

Owing to increasing demand (from 450,000,000 cu. m. per year in 1922 to 1,000,000,000 cu. m. per year in 1952), strict regulations are enforced relating to reservoir construction, both presently and in the future.

A program of treatment of sewage and industrial wastes is rigidly enforced, which includes a diversion of sewage and effluents from the Ruhr to the Rhine River.

Because of the increasing pollution load on the Rhine, treatment works are now planned and under construction.

For treatment on the Ruhr area, modern high-rate trickling filters are planned, in accordance with German practice.

In the purification of the Ruhr itself, the treatment of industrial wastes is essential, either by the Ruhr Association or the industry, particularly to reduce the amount of phenol produced and remove acid pickling waste liquor.

Over the years the Ruhr Association has built and is now operating 80 biological and mechanical treatment plants for the sewage of towns, 25 sewage pumping stations and high water pumping stations, 4 reservoirs in the course of the river to intensify biological self-purification, and 48 treatment plants for industrial wastes.

The total length of collectors for sewage and industrial wastes effluents built by the Ruhrverband is, roughly, 250 kilometers (155 mi.) The reservoirs are available for recreation.

Locks are provided to pass 300-ton barges from the Rhine, with a proposed lockage for 1,200-ton barges.

Similar projects have been developed on the Emscher River. LANGDON PEARSE

Personal Impressions of the Rivers (Prevention of Pollution) Act, 1951. BY J. I. SPICER. *Jour. and Proc. Inst. Sew. Purif.* (Brit.), p. 181 (1952).

A discussion of the technical implications of the Act is followed by an outline of its principal provisions with reference to sewage disposal.

The guiding principles of the act provide that a river board in exercising its powers shall have regard to the character and flow of the stream and to the extent to which the stream is or may be in the future used for industrial purposes, fisheries, water supply, agriculture, transportation, or nagivation. Standards for any stream shall be conclusive on the question of what is or is not poisonous, noxious, or polluting in relation to that stream.

To facilitate discussion, various tentative standards were offered.

The powers given to river boards to withhold consent to new outlets and new discharge, stand alongside prescription of standards and together constitute the essence of the act.

In Part II, the principal provisions of the act are discussed, both as to responsible bodies, extent of application, and existing legislation replaced.

The offenses include use of a stream for disposing of polluted matter; impeding the flow; unlawful cleansing of the bed of the stream; unlawfully allowing cut vegetation to remain in a stream; bringing into use new outlets or making new discharges without consent; discharge of an effluent not complying with conditions imposed.

The limitations on river surveys as to standards to be set and the effluent standards are described in general terms.

LANGDON PEARSE

Twelve Months' Operation of Sand Filtration and Micro-Straining Plant at Luton. BY S. C. EVANS AND F. W. ROBERTS. *Jour. Inst. Sew. Purif.* (Brit.), 333 (1952).

This is the original of a digest published previously (see abs. THIS JOURNAL, 25, 12, 1481; Dec., 1953). H. P. O.

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Proceedings of Member Associations

KANSAS SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

The 1955 Annual Meeting of the Kansas Sewage and Industrial Wastes Association was held April 13–15, 1955, at the Baker Hotel, Hutchinson, Kans., in conjunction with the Kansas Section AWWA.

In addition to panel discussions on sewer and sewage plant odors and their control, sludge treatment and disposal, and plant landscaping, the following papers were presented:

"Oil and Silt Traps at Service Stations and Garages," by Don H. Swezey, Superintendent, Wakefield.

"Incorporating Industrial Wastes in a Municipal Sewer System," by George Fisher, Director of Service, Wichita.

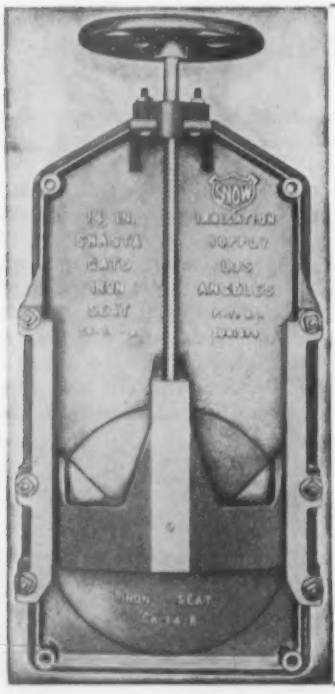
"Unusual Features in Wichita Intercepting Sewers," by W. Smith, City Engineer, Wichita.

Officers elected were:

Chairman: L. Beyer, McPherson.
Vice-Chairman: D. Eller, Junction City.
Secretary-Treasurer: R. H. Hess, Wichita.

The Federation's Arthur Sidney Bedell Award was presented to Leland Talbot, by Federation President David B. Lee.

ROBERT H. HESS,
Secretary-Treasurer



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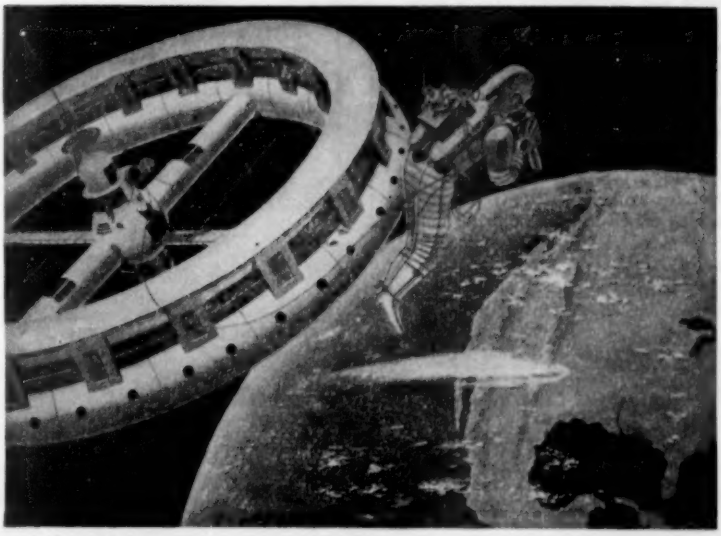

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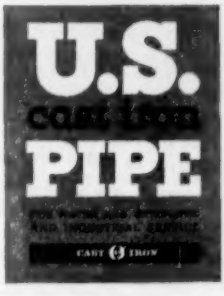

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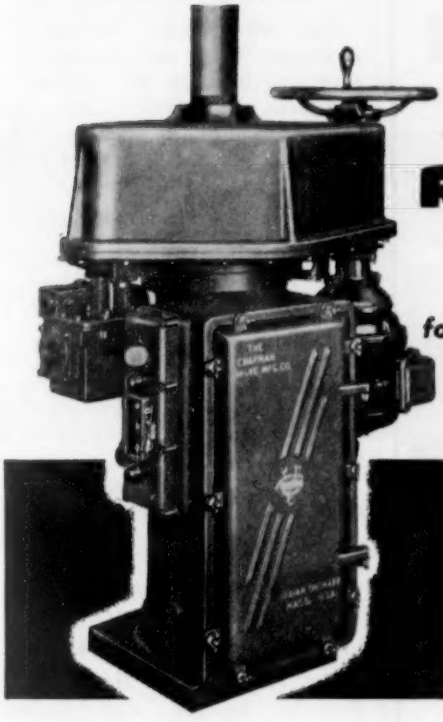

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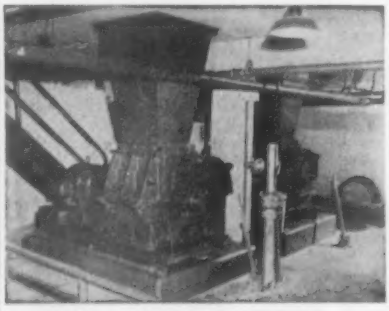

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The 24th Annual Meeting of the Arkansas Water and Sewage Conference was held at the University of Arkansas, Fayetteville, Ark., March 21–23, 1955, in conjunction with the Annual Short School. Total registration was 148.

Officers elected for 1955–6 were:

Chairman: L. J. Embree, Magnolia.
Vice-Chairman: F. Lewis, Mena.
FSIWA Director: L. R. Heiple, Fayetteville.
Secretary-Treasurer: Harrison Hale, Magnolia.

C. H. French was nominated to receive the Federation's Arthur Sidney Bedell Award.

HARRISON HALE,
Secretary-Treasurer

MONTANA SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

The 11th Annual Meeting of the Montana Sewage and Industrial Wastes Association was held at the Finlen Hotel, Butte, Mont., on April 28, 1955.

Following the opening remarks and committee reports, F. F. Palmer and C. W. Brinck commented on recent state legislature of interest to the members. The technical program featured a paper on biofiltration by G. Richard Smith, Englewood, Colo. and a panel discussion on sewer joints and jointing compounds.

An inspection trip was made to the precipitation plant of the Anaconda Copper Mining Co.

The following officers were elected for 1955–56:

Chairman: M. F. Dixon, Billings.
Vice-Chairman: R. Setterstrom, Butte.
Secretary-Treasurer: Harvey W. Taylor, Helena.

HARVEY W. TAYLOR,
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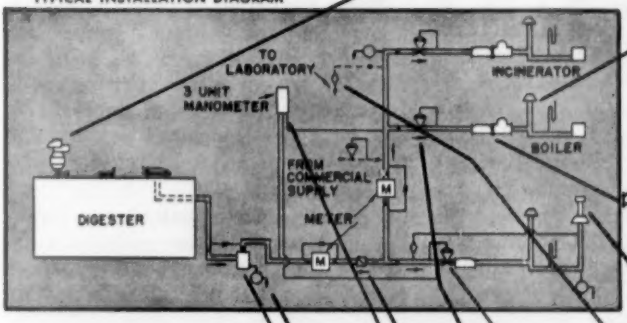

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"VAREC" Check Valve—Fig. 211 or 211A—Controls direction of gas flow.

"VAREC" Manometer—Fig. 215, 215A, 216 or 216A—Indicates system pressures.

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Controller—New Bulletin 7201 describes quick-connect miniature recorder and controller instruments.—Minneapolis-Honeywell Regulator Co., Wayne and Windrim Aves., Philadelphia 44, Pa.

Gas Analyzers—New 20-page brochure No. 0703–3 describes complete line of combustible gas analyzers and alarms—Mine Safety Appliances Co., 201 N. Braddock Ave., Pittsburgh 8, Pa.

Pump Control—Bulletin L2 describes non-clogging, pneumatically-operated wet well pump control.—Builders-Providence, Inc., 345 Harris Ave., Providence, R. I.

Titration Stand—A new support stand for titration use features a sparkling white porcelain base for viewing difficult indicator color changes.—Fisher Scientific, 717 Forbes St., Pittsburgh 19, Pa.

Screening Equipment—New 28-page Book No. 2587 describes and gives specifications for screening equipment to remove solids from water, sewage and industrial wastes.—Link-Belt Co., 307 N. Michigan Ave., Chicago 1, Ill.

Flow Meters—Open channel flow meters for applications involving suspended solids are described in new 12-page Bulletin M22–5.—Bailey Meter Co., 1050 Ivanhoe Rd., Cleveland 10, Ohio.

Level Controller—Leaflet, Form CP2 describes a capacitive-type electronic probe for sensing the level of non-adhesive fluids and operating pneumatic control valves.—Thermo Instruments Co., 1310 County Rd., Belmont, Calif.

Time-Pattern Transmitters—A pneumatic time-pattern transmitter designed to position the set point indices of one or more instruments is featured in Specification Sheet 287-1.—Minneapolis-Honeywell Regulator Co., Wayne and Windrim Ave., Philadelphia 44, Pa.

Circular Chart Controllers—Circular chart pneumatic controllers are described in leaflet S. S. 163-1.—Minneapolis-Honeywell Regulator Co., Wayne and Windrim Ave., Philadelphia 44, Pa.

Malleable Couplings—A 16-page bulletin illustrates many uses and labor saving features made possible by special malleable pipe couplings and fittings.—Gustin-Bacon Manufacturing Co., 210 W. 10th St., Kansas City 6, Mo.

Pneumatic Transmitter—Technical Bulletin 285–L2 describes the advantages, uses, and operation of a newly-developed pneumatic transmitter for measuring liquid levels, flows, and differential pressures.—Builders-Providence, Inc., 345 Harris Ave., Providence, R. I.

Gear Hoists—Spur gear hoists in a wide range of models and capacities are described in Bulletin YC and YCT (8 pages).—Coffing Hoist Co., Danville, Ill.

Clarifier Equipment—Attractive Bulletin 35–D describes a complete line of industrial waste, sewage, and water clarification equipment, together with digesters and sand filters.—Hardinge Co., Inc., 240 Arch St., York, Pa.

Laboratory Stirrer—A power stirrer for laboratory use features a hollow spindle for securely holding stirring rods.—Arthur S. LaPine and Co., 6001 S. Knox Ave., Chicago 29, Ill.

(*Continued on page 336a*)

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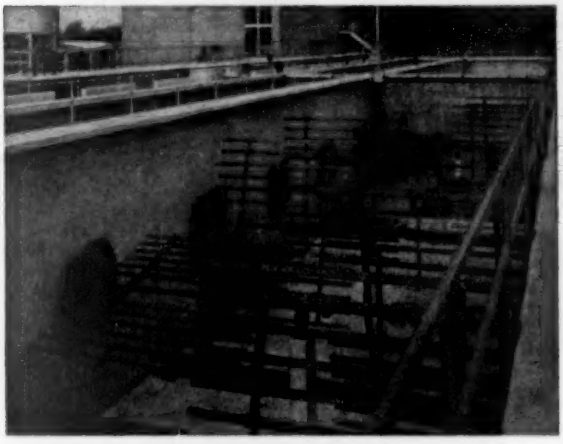

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Chlorinator Operation—Technical Bulletin 840-K13 presents typical installation diagrams and photographs for automatic proportional operation of chlorinators.—Builders-Providence, Inc., 345 Harris Ave., Providence 1, R. I.

Bulk Chemicals—The price of many regularly used reagent—grade chemicals in 100-to 600-lb. drums may be found in the new chemical supplement, "Bulk Chemicals."—Fisher Scientific Co., 711 Forbes St., Pittsburgh 19, Pa.

Check Valves—Spring tension applied to the opening and closing of the swing-type flapper provides non-slam check valve operation in any position.—W. R. Ames Co., 150 Hooper St., San Francisco, Calif.

Municipal Incinerator—Bulletin 601–55 pictures typical installations of various types of municipal incineration plants featuring mechanical stoking systems.—Pittsburgh-Des Moines Steel Co., Neville Island, Pittsburgh 25, Pa.

Pipeline Mixer—Continuous chemical mixing of liquid, gas, or slurry in the pipeline is described in Bulletin 300.—American Well Works, Aurora, Ill.

Water Control Gates—The excellently prepared and indexed Catalog 55 will furnish the design engineer and specification writer with complete technical data on control gates and accessories for water and sewage treatment works. Specifications and data tables are included.—Perkul Gate Div., Morse Bros. Machinery Co., 2900 Brighton Blvd., Denver, Colo.

Electric Check Valve—A double cushioned electric check valve, completely hydraulic with integral power chamber, is reported to solve many problems associated with disc and piston check valves.—Golden-Anderson Valve Specialty Co., 1232 Ridge Ave., Pittsburgh 33, Pa.

Slide Gate—New release pictures a low cost, easily installed aluminum slide gate for full channel flow where closure can be made under balanced conditions.—Rodney Hunt Machine Co., Orange, Mass.

Diaphram Pump—A variable speed, rubber cushioned, vertical stroke plunger is featured on a new diaphram pump constructed of aluminum.—Construction Machinery Co., Waterloo, Iowa.

Metal Grating—Steel grating for armored floors and other uses is described in new releases.—Klemp Metal Grating Corp., 6603 S. Melvina Ave., Chicago 38, Ill.

Gear Drives—New 32-page Book 2619 supplies complete engineering data on parallel shaft gear drives.—Link-Belt Co., 307 N. Michigan Ave., Chicago 1, Ill.

Painting Guide—A ready reference for sewage and water treatment plant painting is the "Engineers' Painting Guide for Sewage Plants and Water Works."—Inertol Co., Inc., 480 Frelinghuysen Ave., Newark 5, N. J.

Air Operated Pumps—Details on pneumatically operated pumps are given in Bulletin UP–55.—Hills-Mc Canna Co., 3025 N. Western Ave., Chicago 18, Ill.

Sewage Ejector Tables—Engineering tables simplifying the selection of clog-proof sewage ejectors are presented in the publication "Flush Kleen Selection 'Made Easy'."—Chicago Pump Co., 622 Diversey Parkway, Chicago 14, Ill.

Multi-Fuel Engines—Colorful new Bulletins E–7 and E–9 illustrate the design features of natural gas-butane-gasoline engines with horsepower ratings from 115 to 675.—Le Roi Div., Westinghouse Air Brake Co., 1706 S. 68th St., Milwaukee 14, Wis.

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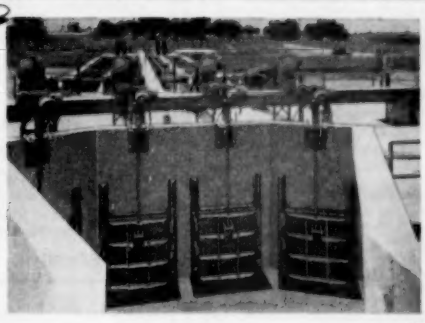

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